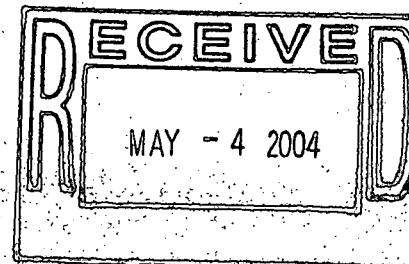


**Technical Memorandum No. 2  
Initial Screening of  
Remedial Technologies and Identification  
Of Remedial Alternatives for  
Operable Unit No. 2**

**U.S. Department of Energy  
Rocky Flats Environmental  
Technology Site  
Golden, Colorado**

**Revision 0**

**May 1995**



ADMIN RECORD

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**PARSONS ENGINEERING SCIENCE, INC.**

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May 19, 1995

Mr. John Hopkins  
Project Manager, CMS/FS Project  
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Subject: Transmittal of Technical Memorandum No. 2, Initial Screening of Remedial Technologies and Identification of Remedial Alternatives for Operable Unit No. 2  
- Revision 0

Dear Mr. Hopkins:

Enclosed please find eleven (11) copies of the subject document for your review and comment. We look forward to your comments.

Please feel free to call me if you have any questions.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

*Timothy C. Shangraw*

Timothy C. Shangraw, P.E.  
Project Manager

cc: Anne Long  
File

022/722463/129.WPF



**Technical Memorandum No. 2  
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**U.S. Department of Energy  
Rocky Flats Environmental Technology Site  
Golden, Colorado**

**Draft**

**May 19, 1995**

**Prepared by  
Parsons Engineering Science, Inc.  
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**Technical Memorandum No. 2 - Initial Screening of Remedial Technologies and  
Identification of Remedial Alternatives for Operable Unit No. 2**

**TABLE OF CONTENTS**

LIST OF ACRONYMS AND ABBREVIATIONS .....	iv
EXECUTIVE SUMMARY .....	vi
1.0 INTRODUCTION .....	1-1
2.0 SITE CHARACTERISTICS .....	2-1
2.1 Site Geology and Hydrogeology .....	2-1
2.1.1 Surficial Geology .....	2-1
2.1.2 Bedrock Geology .....	2-2
2.2 Nature and Extent of Contamination .....	2-2
2.2.1 Source Areas for Surface Soil Contamination .....	2-3
2.2.2 Residual Surface Soil Contamination .....	2-5
2.2.3 Source Areas for Subsurface Soil Contamination .....	2-7
2.2.4 Residual Subsurface Soil Contamination .....	2-8
2.2.5 Upper Hydrostratigraphic Unit (UHSU) Groundwater Contamination .....	2-8
2.2.5.1 UHSU Conceptual Model .....	2-8
2.2.5.2 UHSU Contamination .....	2-9
2.3 Contaminant Fate and Transport .....	2-11
2.3.1 Source Areas for Surface Soil Contamination .....	2-11
2.3.1.1 Intermedia Pathways .....	2-11
2.3.1.2 Intramedia Pathways .....	2-12
2.3.2 Residual Surface Soil Contamination .....	2-12
2.3.3 Source Areas for Subsurface Soil Contamination .....	2-13
2.3.3.1 Intermedia Pathways .....	2-13
2.3.3.2 Intramedia Pathways .....	2-14
2.3.4 Residual Subsurface Soil Contamination .....	2-14
2.3.5 Upper Hydrostratigraphic Unit Groundwater Contamination ...	2-14
2.3.5.1 Intermedia Pathways .....	2-14
2.3.5.2 Intramedia Pathways .....	2-15
3.0 CORRECTIVE/REMEDIAL ACTION OBJECTIVES .....	3-1
4.0 REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS .....	4-1
4.1 Identification of General Response Actions .....	4-1
4.2 Identification of Technologies and Process Options .....	4-2
4.3 Screening of Technologies and Process Options .....	4-3

## TABLE OF CONTENTS (Continued)

4.3.1	Initial Technology Screen	4-4
4.3.2	Technology Evaluation	4-5
4.4	Representative Process Options	4-6
5.0	POTENTIAL REMEDIAL ALTERNATIVES	5-1
5.1	OU2 Surface Soils Source Alternatives	5-1
5.1.1	GRA - No Further Action	5-1
5.1.2	GRA - Institutional Controls	5-2
5.1.3	GRA - Containment	5-2
5.1.4	GRA - <i>In Situ</i> Treatment	5-3
5.1.5	GRA - Removal	5-4
5.1.6	GRA - <i>Ex Situ</i> Treatment	5-5
5.1.7	GRA - <i>Ex Situ</i> Treatment	5-5
5.2	OU2 Subsurface Soils Source Alternatives	5-6
5.2.1	GRA - No Further Action	5-6
5.2.2	GRA - Institutional Controls	5-7
5.2.3	GRA - Containment	5-7
5.2.4	GRA - Containment	5-8
5.2.5	GRA - <i>In Situ</i> Treatment	5-8
5.2.6	GRA - <i>In Situ</i> Treatment	5-9
5.2.7	GRA - <i>In Situ</i> Treatment	5-9
5.2.8	GRA - <i>In Situ</i> Treatment	5-10
5.2.9	GRA - Removal	5-10
5.2.10	GRA - <i>Ex Situ</i> Treatment	5-11
5.2.11	GRA - <i>Ex Situ</i> Treatment	5-11
5.3	OU2 Surface Soils Residual Alternatives	5-12
5.3.1	GRA - No Further Action	5-12
5.3.2	GRA - Institutional Controls	5-12
5.3.3	GRA - Containment	5-13
5.3.4	GRA - Containment	5-13
5.3.5	GRA - <i>In Situ</i> Treatment	5-13
5.3.6	GRA - Removal	5-14
5.3.7	GRA - <i>Ex Situ</i> Treatment	5-14
5.4	OU2 Subsurface Soils Residuals Alternatives	5-14
5.5	Remediation Alternatives for OU2 Groundwater	5-15
5.5.1	GRA - No Further Action	5-18
5.5.2	GRA - Institutional Controls	5-18
5.5.3	GRA - Containment	5-19
5.5.4	GRA - <i>In Situ</i> Treatment	5-20
5.5.5	GRA - <i>Ex Situ</i> Treatment	5-21

## TABLE OF CONTENTS (Continued)

6.0	LOCATION- AND ACTION-SPECIFIC APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS . . . . .	6-1
7.0	FIGURES AND TABLES . . . . .	7-1
8.0	REFERENCES . . . . .	R-1

### APPENDIXES

Appendix A	Description of Soil Technologies and Process Options Passing Technical Implementability Screen	
Appendix B	Description of Groundwater Technologies and Process Options Passing Technical Implementability Screen	

4p

## LIST OF ACRONYMS AND ABBREVIATIONS

Am-241	Americium-241
ARAR	Applicable or Relevant and Appropriate Requirement
AS/SVE	Air Sparging/Soil Vapor Extraction
ATTIC	Alternative Treatment Technology Information Center
C/RAO	Corrective and Remedial Action Objective
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHWA	Colorado Hazardous Waste Act
CCl <sub>4</sub>	Carbon Tetrachloride
CLT	Comprehensive List of Technologies
cm	centimeters
cm/s	Centimeters per Second
CMS/FS	Corrective Measures Study/Feasibility Study
COC	Chemical of Concern
cpm	Counts per Minute
DAA	Detailed Analysis of Alternatives
DNAPL	Dense Non-Aqueous Phase Liquid
DOE	U.S. Department of Energy
EE/CA	Engineering Evaluation/Cost Analysis
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
ft <sup>2</sup>	square feet
ft	foot or feet
FY	fiscal year
GRA	General Response Action
IAG	Interagency Agreement
IHSS	Individual Hazardous Substance Site
IM/IRA	Interim Measures/Interim Remedial Action
kg	kilograms
LNAPL	Light Non-Aqueous Phase Liquid
LHSU	Lower Hydrostratigraphic Unit
m <sup>2</sup>	square meters
m <sup>3</sup>	cubic meters
mg	milligrams
NAPL	Non-Aqueous Phase Liquid
NCP	National Contingency Plan
No.	Number
NTS	Nevada Test Site
OU	Operable Unit
pCi/g	PicoCuries per Gram
pCi/L	PicoCuries per Liter
PCE	Perchloroethylene or Tetrachloroethene

PRG	Preliminary Remediation Goal
Pu-239 +240	Plutonium-239+240
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RFI/RI	RCRA Facility Investigation/Remedial Investigation
ROD	Record of Decision
RPO	Representative Process Option
RREL	Risk Reduction Environmental Laboratory
State	State of Colorado
SVE	Soil Vapor Extraction
SVOC	Semivolatile Organic Compound
SWMS	Soil Water Monitoring System
TBC	To-Be-Considered
TCE	Trichloroethylene
TCLP	Toxicity Characteristic Leaching Procedure
TSVE	Thermally Enhanced Soil Vapor Extraction
TSD	Treatment, Storage, or Disposal
UHSU	Upper Hydrostratigraphic Unit
UST	Underground Storage Tank
VISITT	Vendor Information System for Innovative Treatment Technologies
VOC	Volatile Organic Compound
WAC	Waste Acceptance Criteria

## EXECUTIVE SUMMARY

This technical memorandum addresses the development and screening of technologies and process options, and presents alternatives for the remediation of surface and subsurface soils, groundwater, and contaminant sources associated with Operable Unit 2 (OU2) at the Rocky Flats Environmental Technology Site (RFETS). To address contaminated media, OU2 has been segregated into five remediation areas consisting of the following: (1) source areas for surface soil contamination; (2) source areas for subsurface soil contamination; (3) residual areas for surface soil contamination; (4) residual areas for subsurface soil contamination; and (5) contaminated groundwater.

Corrective/remedial action objectives (C/RAOs), which integrate requirements of both the Resource Conservation Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), have been established for OU2. Based on these C/RAOs, general response actions were developed that address the various contaminated OU2 media. Remediation targets were established in Technical Memorandum No. 1 for OU2 (DOE, 1995a) based on chemical-specific applicable or relevant and appropriate requirements (ARARs) and calculated risk-based concentrations. A comparison of the maximum detected concentrations of chemicals of concern (COCs) against selected remediation targets was conducted. Plutonium-239+240 (Pu-239+240) was identified as the COC which exceeded remediation targets for both source and residual surface soil remediation areas. Tetrachloroethene (PCE) was identified as exceeding the selected remediation target for both source and residual remediation areas for subsurface soil. Additional characterization efforts are in progress to address other COCs in source areas for subsurface soils within OU2. These efforts will be incorporated into an engineering evaluation/cost analysis (EE/CA), which is being prepared under separate cover. Groundwater COCs which exceed the selected remediation targets include carbon tetrachloride, chloroform, 1,1-dichloroethene, methylene chloride, PCE, trichloroethene, vinyl chloride, americium-241 (Am-241), and Pu-239+240.

Remedial technologies were screened using a two-phase process. The initial phase screened technologies from the Comprehensive List of Technologies (CLT) (EG&G, 1994) for technical implementability based on OU2 site-specific characteristics. The second phase consisted of an evaluation of effectiveness, institutional implementability, and relative cost. The screening process removed technologies from further consideration that could not be implemented because of site-specific factors, thereby reducing the number of remedial technologies and process options for consideration in the development of remedial alternatives. Representative process options were then selected from the screened list of technologies.

Remedial alternatives were developed for each of the five remediation areas of OU2 and are summarized in the alternatives matrix presented in Table 1.1. A general description of the remedial alternatives is provided in Section 5.0. All alternatives will be evaluated in further detail in the detailed analysis of alternatives (DAA) section of the OU2 corrective measures study/feasibility study (CMS/FS).

## 1.0 INTRODUCTION

Various areas of the Rocky Flats Environmental Technology Site (RFETS) are being remediated in accordance with provisions of the 1991 Interagency Agreement (IAG) between the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the State of Colorado (State) (IAG, 1991). The IAG integrates closure and corrective action provisions of the Resource Conservation and Recovery Act (RCRA) and the Colorado Hazardous Waste Act (CHWA) with the hazardous substance response requirements contained in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to ensure protection of human health and the environment.

The various areas to be remediated, called individual hazardous substance sites (IHSSs), are grouped into 16 operable units (OUs). As outlined in Section IX.B of the IAG statement of work, remedial alternatives for the corrective measures study/feasibility study (CMS/FS) for each OU are to be developed and screened. This technical memorandum addresses the development and screening of technologies and process options, and presents alternatives for the remediation of surface soils, subsurface soils, and groundwater associated with Operable Unit 2 (OU2).

This technical memorandum is intended to fulfill requirements specified in the IAG statement of work, Sections IX.A.2 to IX.A.5 for OU2. These IAG requirements include:

- Developing general response actions (GRAs) (see Section 4.0);
- Identifying areas and volumes of contaminated media (see Section 2.0);
- Identifying and screening corrective/remedial technologies (see Section 4.0); and
- Assembling the potential technologies into alternatives (see Section 5.0).

This technical memorandum contains seven sections, including this introduction, plus two appendices. Section 2.0 of this document briefly describes site characterization information for OU2 that has been obtained through the RCRA facility investigation/remedial investigation (RFI/RI). In addition, Section 2.0 provides the location and volumes of contaminated media in each remediation area. Section 3.0 contains the corrective and remedial action objectives (C/RAOs). Section 4.0 presents the GRAs and results of the initial screening process for potential remedial technologies and process options. Section 5.0 presents the grouping of remedial technologies into remedial alternatives for each of the remediation areas. Section 6.0 identifies potential location- and action-specific applicable or relevant and appropriate requirements (ARARs) for each remedial alternative. Figures and tables are provided in Section 7.

## 2.0 SITE CHARACTERISTICS

OU2 is one of 16 OUs at the RFETS and, as shown in Figure 2.1, is located on the southeastern side of the RFETS industrial area. OU2 contains 22 IHSSs that have been organized into five remediation areas based on contaminated media and type of contamination (i.e. source vs. residual). These five remediation areas include source areas for surface soil contamination, source areas for subsurface soil contamination (potential or current), residual areas for surface soil contamination, residual areas for subsurface soil contamination, and upper hydrostratigraphic unit (UHSU) groundwater contamination. The locations of the individual IHSSs are shown on Figure 2.2. A matrix identifying the individual IHSSs in relation to the five remediation areas is presented in Table 2.1.

This section provides a brief description of the site geology (Section 2.1), the nature and extent of contamination (Section 2.2), and the fate and transport mechanisms for the chemicals of concern (COCs) (Section 2.3). The information provided in this section is a summary of the site characterization results presented in the preliminary draft OU2 RFI/RI report (DOE, 1993), Technical Memorandum No. 9 for OU2 (DOE, 1994b), and Technical Memorandum No. 1 for OU2 (DOE, 1995a).

### 2.1 Site Geology and Hydrogeology

A brief summary of OU2 surficial and bedrock geology is presented below.

#### 2.1.1 Surficial Geology

Surficial geologic units within OU2 consist of alluvial, hillslope, and man-made deposits. Alluvial deposits include the Pleistocene-aged Rocky Flats Alluvium, younger terrace alluvia, and various Holocene-aged valley-fill alluvia. Hillslope deposits consist of Holocene-aged colluvium and landslide slumps. Man-made deposits are artificial fills, debris dumps, and areas of disturbed surficial soil. A brief summary of the surficial deposits is presented below.

**Rocky Flats Alluvium** - The Rocky Flats Alluvium is the topographically highest and oldest alluvial deposit at RFETS. The Rocky Flats Alluvium within OU2 caps the pediment surface between South Walnut and Woman Creeks. The pediment is completely truncated to the north, east, and south by these modern drainages. The Rocky Flats Alluvium within the OU2 area consists predominantly of beds and lenses of poorly to moderately sorted gravels and sands. A few lenses of clay and silt also occur.

**Hillside Deposits** - Hillside deposits within the OU2 area include several alluvial terrace deposits, valley-fill alluvium, colluvium, and landslide slumps. Slump features belong to two categories: 1) areas along the hillsides which exhibit evidence of mass movement of surficial soil and possibly bedrock materials along relatively distinct ruptures or glide surfaces, and 2) areas of hummocky topography reflecting downslope creep of surficial soils but no observable rupture surface.

**Man-Made Deposits** - Man-made deposits within the OU2 area have been identified using information from historical reports, air photography, and geologic field mapping. Three general categories of man-made deposits have been identified: soil and debris dumps, disturbed ground, and artificial fill.

### **2.1.2 Bedrock Geology**

Bedrock geologic units within the OU2 area consist of claystones, siltstones, and sandstones. The No. 1 Sandstone is considered the basal part of the Arapahoe Formation. All lower bedrock units are considered to be a part of the upper Laramie Formation (DOE, 1993).

**Arapahoe Formation No. 1 Sandstone** - Subsurface investigations have shown that the Arapahoe Formation No. 1 Sandstone (No. 1 Sandstone) is a distinct bedrock unit separate in geologic characteristics from the underlying Laramie Formation. Most of the No. 1 Sandstones are predominantly fine- to medium-grained and represent deposition in low to moderate flow regimes. The No. 1 Sandstone is the stratigraphically highest sandstone encountered within the OU2 area. It is stratigraphically located from 0 to 20 feet below the overlying surficial deposits. The sandstone directly underlies the Rocky Flats Alluvium along a medial paleoscur beneath OU2. Prior to deposition of the Rocky Flats Alluvium, erosion of the claystone/siltstone material in this area created the paleoscur. The resulting subcrop area beneath the Rocky Flats Alluvium is an important feature in that it allows vertical groundwater flow to the No. 1 Sandstone from the overlying alluvial units.

**Laramie Formation** - The Laramie Formation is a fresh-to-brackish-water, non-marine deposit. Lithologic logging of the upper Laramie Formation suggests that in this area it is largely composed of claystone with lenses of fine-grained sandstone. The most common upper Laramie Formation lithologies encountered in boreholes within the OU2 area are claystones and silty claystones. The upper Laramie Formation sandstone or siltstone interbeds are approximately 10 feet thick, except where interbeds are stacked on top of each other. Where sandstone interbeds are stacked, a thicker sandstone sequence results. The sandstone interbeds are commonly separated by thin siltstone or claystone layers.

## **2.2 Nature and Extent of Contamination**

The remediation targets selected for OU2 were compared against the maximum detected concentrations of each COC to identify those contaminants that warrant further consideration in the CMS/FS process. If the maximum concentration was less than the respective remediation target, the COC was eliminated from further consideration. For the purposes of identifying and evaluating potential remedial technologies, only those COCs with concentrations in excess of the OU2 remediation target levels were retained in the CMS/FS process. The results of this comparison for surface soils, subsurface soils, and groundwater are provided in Tables 2.2, 2.3, and 2.4, respectively. The comparison of maximum concentrations of each COC against the selected remediation targets provides a more restrictive basis for assessing nature and extent of

contamination and development of remedial alternatives than the use of average concentrations; therefore, the volume estimates could represent an over-estimation of actual contaminant volumes.

Several of the IHSS located in OU2 do not contain COCs in concentrations exceeding the remediation targets developed in Technical Memorandum No. 1. These IHSSs include the East Spray Fields (IHSS 216.2-3), Gas Detoxification Site (IHSS 183), Oil Burn Pit Site No. 2 (IHSS 153), Pallet Burn Site (IHSS 154), and Reactive Metal Destruction Site (IHSS 140). Since these IHSSs do not require remedial actions based on the remediation targets, they will not be addressed further in this document.

For purposes of identifying and evaluating potential remedial technologies, the extent of contamination for each IHSS was compared against the selected remediation targets to identify those IHSSs which warranted further consideration in the CMS/FS process. The results of this comparison are presented in Table 2.5. Further discussion concerning the nature and extent of contamination by remediation area is provided in the following paragraphs.

### **2.2.1 Source Areas for Surface Soil Contamination**

Source areas for OU2 surface soils have been defined as localized areas of elevated contaminant concentrations that have historically acted as sources of contamination. This consists of the former drum storage site (903 Pad) and the 903 Pad Lip.

#### **903 Pad**

The 903 Pad was a graded earthen area located at the southeast corner of the industrial area, and was used for storage of waste drums between 1958 and 1967. The drums contained machine oil (primarily lathe coolant consisting of straight chain hydrocarbons with carbon tetrachloride), hydraulic oils, vacuum pump oils, trichloroethylene (TCE), perchloroethylene (PCE), silicone oils, and acetone still bottoms contaminated with either plutonium (Pu) or depleted uranium. Contaminated oil reportedly leaked from approximately 420 drums located on the 903 Pad. This resulted in the release of an estimated 18,000 liters (5,000 gallons) of liquid and 86 grams (Seed et al., 1971) to 126 grams (Krey and Hardy, 1970) of Pu-239+240 to the soil environment.

In 1960, a radiological survey at the 903 Pad indicated that the pad area and the surrounding (lateral) 10 feet of surficial soils were contaminated with Pu-239+240 and depleted uranium. By 1964, evidence of large-scale deterioration of drums was reported and fill dirt was placed on highly contaminated areas on the 903 Pad. Surveys performed in the Lip Area in 1967 revealed spreading of contamination; dispersion (surface transport) was attributed to a heavy rain event. Soil and rocks (east and downgradient of the storage area) contaminated by rainwater runoff from the fenced area were hand excavated and deposited inside the 903 Pad fence (DOE, 1992).

Drum removal activities from the 903 Pad began in 1968. Following drum removal radiological monitoring detected elevated levels of contamination in the surrounding areas. Contaminant dispersion was attributed to high velocity winds. Radiation monitoring and mapping of the 903 Pad area documented radiological contamination to a depth of 20.3 centimeters (cm) (8 inches).

Fill material, for leveling, was applied to the 903 Pad in 1969. Additionally, overlay material, soil sterilant, and an asphalt cover were placed over the 903 Pad (DOE, 1992). In 1970, 6 inches of coarse road base was applied to the Lip Area.

During monitoring of the 903 Pad in 1971, four "hot spots" were identified based on radiological surveys. This led to the removal of 31 kilograms (kg) of depleted uranium and up to 10.3 milligrams (mg) of Pu from beneath the asphalt cover. During sampling activities associated with this removal action, an oil layer, contaminated with depleted uranium, was discovered at two separate boreholes at depths of 45.7 and 76.2 cm (18 inches and 30 inches) respectively at the holes where the 31 kg of depleted uranium were extracted. A clay layer was noted beneath the contaminated zone. At that time, no contamination was found below the clay layer, and it was believed that the layer served as a natural barrier to downward migration of contaminants. However, the draft OU2 RFI/RI identified radiological contamination at decreasing concentrations from 0.6 to 6 meters (2 to 20 ft). Volatile organic compound (VOC) contamination was found at depths to 7.3 meters (24 ft).

### 903 Lip Area

Prior to the addition of an asphalt cap, contamination present at the 903 Pad was transported by winds and surface water runoff (immediately following drum removal activities) and were deposited on soils in an east and southeast trending plume (Krey and Hardy, 1970; Seed et al. 1971). The analysis of spatial distribution identifies a west to east wind transport mechanism being the dominant dispersal mechanism of Pu-239+240.

Contaminated soil in this Lip Area, identified in the past though Fidler (non intrusive survey equipment) monitoring and laboratory analysis, has been excavated. In 1973, an aerial radiological survey detected radioactive concentrations in the Lip Area that were greater than 2,000 counts per minute (cpm). In 1975, eight 55-gallon drums of soil were removed from the contaminated Lip Area, as a pilot test for excavation techniques. Ambient air monitoring during excavation did not detect Pu in concentrations that would endanger onsite workers, the public, or the environment. In 1976, approximately 113.3 cubic meters (m<sup>3</sup>) (4,000 cubic feet) of soil were removed from the within the Lip Area. Soil removal activities were conducted again in 1978 covering an estimated 3,995 m<sup>2</sup> (43,000 ft<sup>2</sup>) at a depth of approximately 3.5 cm (9 inches) for soil that exceeded 2,000 cpm. This targeted area is believed to have been the topical depression southeast of the 903 Pad. After each removal action the excavated area was covered with clean fill and revegetated. Historical aerial photographs verify this conclusion.

Although several removal actions have been conducted in the 903 Lip Area, recent sampling has detected the presence of Pu-239+240. The vertical profile of actinides in the fill region follows a unique profile with depth. In general, the highest activity is found in the top 3 cm (1.2 inches), followed by a significant decrease between 6 and 9 cm (2.4 and 3.4 inches), then by an increase in actinide activity beneath the fill level. The increase of actinide activity in the top 3 cm (1.2 inches) of fill material cannot be explained by previous wind dispersion.

Soil sampling conducted during the RFI/RI indicated levels of Pu-239+240 in the Lip Area above the 1,800 picoCuries per gram (pCi/g) remediation target. The extent of contamination was denoted by generating OU2 isopleth maps of Pu-239+240, based on RFI/RI analytical results for the COCs (See Figures 2.3 and 2.4). During the Lip Area removal activities in 1976 and 1978 an additional 20 cm of fill were added. The areal extent of current Lip Area contamination is approximately 10,000 m<sup>2</sup> (107,600 ft<sup>2</sup>) in size. Assuming a depth of 40 cm (including the 20 cm of fill material that were added to the previously excavated Lip Area), the volume of contaminated media that exceeds the remediation target is estimated to be 4000 m<sup>3</sup> (141,200 ft<sup>3</sup>) of soil.

No other COCs have been detected at concentrations greater than the OU2 remediation target.

### 2.2.2 Residual Surface Soil Contamination

Residual surface soil contamination is defined as contamination present in the upper 5 cm (2 inches) of impacted soil primarily to the east and southeast of the 903 Lip Area. This consists of most of the buffer zone east of the 903 Pad and Lip Area. Those OU1 surface soils contiguous to OU2 which are contaminated with low-levels of plutonium are being administratively addressed under OU2. This is because this area of OU1 surface soil is believed to have been contaminated by the 903 Pad Area.

Contamination in the surface soil residual area is attributed primarily to wind dispersion from the 903 Pad source area. A small amount of Pu contamination originated from the stack effluent of the production facilities. The spatial distribution of Pu-239+240 where this region is adjacent to the source area is displayed in Figure 2.5. The data in this table indicate a large variability in Pu-239+240 activity near the source area between samples taken by Colorado Department of Public Health and Environment (CDPHE) sampling protocols and those which were taken by Rocky Flats sampling techniques.

Plutonium-239+240 was detected in OU2 residual surface soils in concentrations greater than the OU2 remediation target level. Two sample locations, associated with two 2.5-acre plots outside of the Lip Area, detected Pu-239+240 activity greater than 1800 pCi/g outside of the 903 Pad Lip Site. In one of these plots, two field duplicates were taken using the Rocky Flats sampler. One sample exhibited 380 pCi/g and the other showed 11,000 pCi/g. This variability probably occurred due to wind erosion, some solubility and leachability, and the "hot particle" phenomenon. As defined by Winsor and Whicker (1979), a "hot particle" has an activity above

450 pCi/g, and it is usually an agglomeration of numerous host soil grains and  $\text{PuO}_2$ . Studies conducted at Rocky Flats indicated a significant variation in the sizes and spatial distributions of the Pu particles in the soil. Pu oxides are insoluble under OU2 soil conditions, and are subject to heterogeneous dispersion. Therefore, a large variability in a short sampling interval is not surprising. Additionally, the soil sampling techniques at Rocky Flats collect large quantities (up to 5 kg), of which only a small fraction is processed and analyzed. This could explain the variation in actinide activities shown in Figure 2.5.

Other possible causes of the large variability in actinide activity across the remediation area is prior vehicle and construction disturbance and past cleanup practices. A 1994 air photograph taken by the Radiological Assessment Group showed that large vehicular and/or construction disturbances occurred in at least one sampling plot. Based on the required sampling protocol requiring 5 to 10 subsamples in the middle of the plot, samples could have been taken in a highly disturbed location which is unrepresentative of the original loading.

Extensive excavation in 1976 and 1978 in the first plot to the southeast of the 903 Pad could also have affected the distribution of actinide activity. Since Pu activities prior to the cleanup exceeded 10,000 pCi/g, wind and runoff during cleanup probably spread the original contamination to the southeast. This would explain the high readings (up to 5,700 pCi/g) in this area.

Based on current measurements, the volume of contaminated media that exceeds the remediation target is estimated to be 1,070  $\text{m}^3$  (1,400  $\text{yd}^3$ ), assuming a 2-hectare (5-acre) plot at a 5 cm (2 inches) depth. However, the large variability in measured Pu-239+240 activity just east-southeast of the 903 Pad has implications in delineating potential cleanup areas. It is probable that expanded sampling and analysis of Pu-239+240 activity in this region could result in a larger area of concern, perhaps by as much as 20.2 hectares (50 acres). This would increase the remediation volume by 10,700  $\text{m}^3$  (14,000  $\text{yd}^3$ .) Further study should be conducted to determine the actual extent of Pu-239+240 activity in this region.

In regard to vertical distribution of actinide activity in this surface soil source region near the 903 Pad, more than 90 percent (and over 95 percent of detected activity outside of the Lip Area) of the Pu-239+240 is confined to the upper 12 cm (5 inches) of the soil, regardless of the soil series, or distance and direction from the 903 Pad (Litaor et al., 1994). The vertical profile depends on the initial loading of Pu-239+240 on the soil surface; the higher the initial loading, the greater the potential for translocation of actinides with depth. Also, the actinides are most closely associated with soil organic matter. Sequential extraction experiments showed that 45 to 65 percent of the Pu-239+240 is associated with organic matter, 20 to 40 percent is bound to sesquioxides, and 10 to 15 percent probably resides as  $\text{PuO}_2$  particles, loosely associated with primary minerals (Litaor et al., unpublished data).

### 2.2.3 Source Areas for Subsurface Soil Contamination

Source areas for OU2 subsurface soil contamination have been defined as IHSSs which were used as storage or disposal sites for low-level, hazardous, or mixed wastes. These areas may or may not currently contain waste material (e.g., spent solvents, cutting oils, and drums). Additional field characterization efforts have been initiated to better quantify the nature and extent of contamination at these source areas. This characterization and discussions on the nature and extent of contamination will be included in the engineering evaluation/cost analysis (EE/CA). Subsurface soil source areas for OU2 include the Mound Site and Trenches T-1 through T-13. These removal actions are expected to be remedial in nature.

Based on information in the draft RFI/RI report for OU2, contaminant concentrations for the soils beneath the 903 Pad currently do not exceed the remediation targets. Because there is a groundwater contaminant plume beneath the 903 Pad, it is assumed that the 903 Pad was and may currently be a source of contaminants to the groundwater (the remediation targets for groundwater are much lower than the targets for subsurface soils).

The Mound Site was used to dispose of drums containing depleted uranium and beryllium-contaminated lathe coolant. Some drums containing PCE were also placed in the Mound Site. In the past, waste materials were removed from the Mound Sites and were either shipped offsite for disposal or sent to Building 774 for treatment.

The trenches (T-1 through T-13) were used primarily for the disposal of sanitary sewage sludge contaminated with uranium and plutonium, and flattened empty drums contaminated with uranium (DOE, 1992). Plutonium- and uranium-contaminated asphalt planking from the solar evaporation ponds may have been placed in trenches T-4, T-11, and/or other trenches. It is also suspected that some solvent-bearing wastes were placed in some of the trenches; however, it is not known which of the trenches received the wastes. Records indicate that approximately 125 drums containing depleted uranium chips and small amounts of lathe coolant were buried in Trench T-1. This trench is believed to have also received drums containing metal turnings, still bottoms, cemented cyanide waste, and copper alloy. Trench T-9 is reported to contain scrap metal from production operations.

The trenches are currently being characterized as part of an effort to delineate the extent of contamination in the Northeast Trench area. The only COC which was detected in the subsurface soil source area at concentrations exceeding the OU2 remediation target level was PCE. However, it is recognized that only limited characterization data are available for the burial trenches. For the purposes of identifying potential remedial technologies and alternatives, technologies that could be utilized to remediate a wide range of contaminants and debris were evaluated.

#### **2.2.4 Residual Subsurface Soil Contamination**

Residual subsurface soil contamination is defined as contamination remaining in subsurface soils after completion of subsurface source removal actions. The subsurface soils consist of all OU2 soils deeper than approximately 5 cm (2 inches) (EPA, 1992a).

Characterization efforts conducted in support of the RFI/RI for OU2 identified PCE as the only COC occurring at concentrations greater than the OU2 remediation target level. Concentrations of PCE exceed the remediation target of 2,210 mg/kg at two borehole locations (10191 and 24793). Both borehole locations lie in or near Trench T-3 at the Northeast Trench Area and may be addressed in any remedial actions taken at the Subsurface Soil Source Area. It is suspected that waste materials and liquid solvent waste stored in Trench T-3 may have been encountered during the drilling of the boreholes. No other boreholes exceeded the remediation target.

The extent of contamination that exceeds the remediation targets could significantly increase if modeling demonstrates that lower levels of PCE in the subsurface soils are not protective of groundwater. In this case, the remediation target level could potentially be lowered. Such a groundwater protection based remediation target will be developed in the detailed analysis of alternatives.

#### **2.2.5 Upper Hydrostratigraphic Unit (UHSU) Groundwater Contamination**

The nature and extent of groundwater contamination is addressed first by describing the conceptual hydrogeologic model of the site, followed by a discussion of the nature and extent of contamination observed during the RFI/RI.

##### **2.2.5.1 UHSU Conceptual Model**

Within OU2, the UHSU is comprised of variably and seasonally saturated parts of the unconsolidated surficial deposits, the No. 1 Sandstone that is in hydraulic connection with the saturated surficial materials, and weathered claystones of the Arapahoe and/or Laramie Formations. Laramie Formation sandstones that subcrop beneath the No. 1 Sandstone or saturated surficial soils also are considered part of the UHSU. The unconsolidated surficial deposits consist of the Rocky Flats Alluvium, colluvium, valley fill alluvium, and disturbed ground. Groundwater is present in the UHSU under unconfined conditions, except where parts of the No. 1 Sandstone are overlain by claystone, which results in both confined and unconfined conditions within the sandstone. Figure 2.6 presents a schematic cross-section of the site hydrostratigraphy.

The UHSU is located over the relatively flat divide of South Walnut Creek and Woman Creek and is truncated to the north, east, and south along these drainages. The thickness and geometry of the UHSU geologic units are controlled by bedrock paleotopography, specifically the north and south paleoridges that generally trend east-northeast; the medial paleoscar that

lies between the two paleoridges; other bedrock paleotopographic lows and steps that exist on the weathered bedrock paleotopographic surface; and depositional channels of the sandstones included in the UHSU. A bedrock paleotopographic map is provided in Figure 2.7

Groundwater flow within the UHSU is complex because of variations in groundwater flow directions, interactions between geologic units, and variations in degree of saturation and saturated thickness. Groundwater flow within the UHSU is strongly influenced by the bedrock paleotopography and the geometry and hydraulic characteristics of the unconsolidated deposits comprising the UHSU. Groundwater within the UHSU generally is found within the area described as the medial paleoscur (Figure 2.7) and generally flows towards the northeast. In the area of Trench 2, immediately south of the drum storage site, groundwater locally flows to the south during high-water table conditions.

The areal extent and saturated thickness of the UHSU within the medial paleoscur vary seasonally. The north and south paleoridges restrict groundwater outflow from the alluvium to the north and south. The medial paleoscur is erosionally truncated along the north-facing hillslope of South Walnut Creek. UHSU groundwater discharges from the No. 1 Sandstone as seeps from this area.

Groundwater recharge to the UHSU within OU2 occurs as direct infiltration of precipitation, and by lateral and downward seepage from surface water features such as ditches. Recharge to the No. 1 Sandstone probably occurs from infiltration of precipitation and surface water through the overlying unsaturated surficial deposits, vertical groundwater flow from the overlying saturated surficial deposits, and inflow from the saturated sandstone units upgradient (west) of OU2.

#### **2.2.5.2 UHSU Contamination**

Contamination in the UHSU groundwater exists throughout OU2. Source areas for UHSU groundwater contamination are not clearly defined, but may originate from one or more waste disposal or storage sites as defined in the RFI/RI. For purposes of the CMS/FS, groundwater contamination is considered to be non-IHSS specific. Since the source of surface water contaminants (seeps) is believed to be groundwater, the seeps are being addressed as part of the groundwater remediation effort. With implementation of appropriate groundwater controls, the seeps can be remediated. Therefore, separate surface water contaminants and potential exposure pathways are not being considered as part of this technical memorandum.

Results of the Phase II RFI/RI investigation have indicated that the contamination is confined to the UHSU. Characterization efforts conducted in support of the RFI/RI indicate the presence of organics and radionuclides in sufficient quantities to be deemed as COCs within the UHSU of the 903 Pad Area, the Mound Area, and East Trenches Area. Contaminants detected include 1,1-dichloroethene, carbon tetrachloride (CCl<sub>4</sub>), chloroform, methylene chloride, PCE, TCE, vinyl chloride, americium (Am)-241, and Pu-239+240. All of the COCs exceed their respective remediation target.

Groundwater sampling has shown several plumes of VOC contamination in the Rocky Flats Alluvium and the No.1 Sandstone, originating at the 903 Pad, the Mound Area, and the Northeast Trenches Area. Once in the sandstone, the contaminated groundwater flows from the 903 Pad, to the Mound Area, and finally to the Northeast Trenches Areas. As groundwater passes beneath each of these sources, contaminant concentrations increase (DOE, 1995b).

The potential for the occurrence of dense nonaqueous phase liquids (DNAPLs) in groundwater appears to be greatest for  $\text{CCl}_4$ , PCE, and TCE, based on the observation of groundwater concentrations that exceed 1 percent of the chemical solubility. Potential DNAPLs in groundwater could exist beneath the 903 Pad ( $\text{CCl}_4$ , PCE, and TCE), in the vicinity of Trench T-2 (PCE and TCE), north and northeast of the mound site (PCE), and northeast of Trench T-3 and north of Trench T-4 in the Northeast Trenches (TCE). Direct evidence of DNAPLs in groundwater was not observed during the Phase II RFI/RI programs (DOE, 1993).

Pu-239+240 was observed in filtered and unfiltered UHSU groundwater samples collected from wells east and southeast of the 903 Pad. Radionuclide contamination could be associated with high concentrations of VOCs observed in the UHSU in the 903 Pad Source Area (DOE, 1995b).

The extent of groundwater contamination was estimated using analytical results from the second quarter 1992 sampling event. For each of the seven organic COCs, the RFI/RI report provides an isoconcentration map for both the alluvial/colluvial and the No. 1 Sandstone units. In general, the unit-specific isoconcentration maps for each of the COCs are consistent with each other, which may be an indication that their sources and transport mechanisms are similar.

To provide an overall estimation of the contaminant volume for groundwater, the areas exceeding the remediation targets for each individual COC were superimposed to establish a single plume map that encompassed all of the contaminated areas. Contaminant data from both the alluvial/colluvial and No. 1 Sandstone units were combined in the event that the selected remedy is not able to isolate the contaminants between the two units. The combination of the two geologic units also provides a larger estimate of the contaminant volumes.

After the combined plume map was generated, it was combined with the alluvial/colluvial saturated thickness map for the second quarter 1992 sampling event. The second quarter of 1992 was chosen as the baseline for the volume estimate since this time period represents the greatest known saturated thickness of the hydrogeologic units. Since the contaminant plume extends beyond the zone that is saturated year-round, some contaminants may be trapped in the vadose zone as the groundwater recedes.

Based on the distribution of groundwater contamination within the UHSU and the UHSU's maximum saturated thickness, the quantity of contaminated groundwater was estimated in the Phase II RFI/RI report to be about 27 million gallons during wet periods. This estimate was calculated using an average total porosity of 0.361. The total porosity is based on data collected from the Rocky Flats Alluvium in OU4. (The paper by Fedors and Warner, 1993,

contains Rocky Flats Alluvium porosity and hydraulic conductivity data from only one point, #1 Qrf, in OU2. The porosity at this location is 0.506 and is from a very fine grained clayey Rocky Flats Alluvium. This location is on the distal end of the OU2 pediment and porosity values from this area are considered less representative of the 903 Pad area than OU4 data. This paper does not address the Arapahoe Formation No.1 Sandstone.)

No measured values of effective porosity of the Rocky Flats Alluvium are known. The volume of contaminated groundwater present in the UHSU varies seasonally because of the fluctuating water levels. The estimated volume of contaminated groundwater during a drier period (first quarter of 1992) is about 9 million gallons.

## **2.3 Contaminant Fate and Transport**

Contaminant migration pathways including intermedia (transport between two separately defined media) and intramedia (transport within an individual medium) for source surface soil, residual surface soil, source subsurface soil, residual subsurface soil, and groundwater areas are presented below.

### **2.3.1 Source Areas for Surface Soil Contamination**

#### **2.3.1.1 Intermedia Pathways**

The intermedia pathway of surface soil contaminant migration from the 903 Lip Area is the transport of Pu-239+240 from the top 40 cm (16 inches) of soil within IHSS 155 to deeper soils. Transport mechanisms from surface soil to subsurface soils appear to be limited.

Colloid-facilitated transport of radionuclides may be associated with rain or snowmelt. Data for samples of infiltrating water strongly suggest a short residence time of 2 to 4 hours for freely flowing water in the soil system. This short residence time inhibits a continuous interaction between the soil and the flowing water, which helps explain the uniformity in alkalinity, specific conductance, and pH across the study site and between sampling depths. A soil water monitoring system (SWMS) was installed to gather real-time data on freely flowing soil interstitial waters, water content, matric potential, soil temperature, and precipitation. Measurements of soil moisture, matric potential, precipitation, and volume of collected freely flowing waters suggest that preferential flow might occur under both unsaturated and saturated conditions.

However, during the summer of 1993, an evaluation of water and actinide movement was conducted by studying natural and simulated rain events. The actinide activities in water samples from depths of 55 to 80 cm did not exceed 10 pCi/l even after a rain simulation of a 100 year event. This restriction in actinide movement may occur due to a strong affinity between organic soil components and plutonium oxides. Additional rain simulations were run in the summer of 1994 to assess the potential for actinides to be transported downhill by runoff. Three sequential rain simulations of 100 year flooding events were conducted. In these runs,

most of the actinides were relatively immobile (Figure 2.8). However, when the soil moisture regime was changed from aridic to aquatic, significant amounts of Pu-239+240 and Am-241 were transported to groundwater in at least one occurrence. This supports the previous detection of Plutonium in groundwater from a well installed in the colluvium.

### **2.3.1.2 Intramedia Pathways**

Although several removal actions, including the placement of clean fill, have been conducted in the 903 Lip Area, recent sampling has confirmed the presence of Pu-239+240 in the clean fill. This movement of actinides within various surface soil horizons, as demonstrated by the increase of actinide activity in the top 3 cm (1.2 inches) of fill material, cannot be explained by previous wind dispersion.

Based on the site history and other information, burrowing animals, ant colonies, and especially earthworms (which have all been observed at OU2) are believed to be the upwardly mobile transport mechanisms for residual contamination that remained in the Lip Area (Litaor et al., 1994). Earthworm activity is probably the pathway for vertical migration of radionuclides within the top 40 cm (15.7 inches) of the soils investigated (Litaor et al., 1994). Geological features of the site, such as lateral discontinuities and macroporosity, could also contribute to the redistribution of contaminants.

The current dominant intramedia transport of surface soil Pu-239+240 contamination from the 903 Lip Area is biological activity (e.g., earthworms). Rodents may also enhance transport flow. Earthen mounds produced by ants may have increased wind erosion of the soil surface and affected eolian transport of soil particles containing Pu-239+240 (Winsor and Whicker, 1979). Transport mechanisms (wind dispersion and precipitation runoff) potentially exist if the soils or the current vegetative cover are disturbed as was experienced during the original cleanup efforts. Air monitoring results conclude that after the pad was installed in 1969, levels of wind dispersed contamination were significantly reduced. Subsequent air monitoring during the excavation efforts in 1976 and 1978 did not indicate dispersion of contamination via windblown particulates. Currently, this wind dispersion transport mechanism does not appear to be significant due to the presence of a natural vegetative cover, and the absence of significant sources of actinide particles exposed to the ground surface.

Rain simulations conducted to evaluate surface transport mechanisms, found that actinides did not migrate in runoff waters until the end of the second sequential 100-year rain event. This indicates that such migration can only occur under the most extreme and unlikely conditions.

### **2.3.2 Residual Surface Soil Contamination**

The contaminant fate and transport mechanisms for residual surface soil contamination is the same as those described under Source Area for Surface Soil Contamination (Section 2.3.1).

### 2.3.3 Source Areas for Subsurface Soil Contamination

#### 2.3.3.1 Intermedia Pathways

The intermedia pathway of subsurface soil contaminant migration is the transport of contaminants from subsurface soil to groundwater. Characterization of contaminants in the subsurface soil sources has not been completed.

VOCs, semivolatile organic compounds (SVOCs), and/or radionuclides leaked released to subsurface soils at the 903 Pad Drum Storage Site, the Mound Site, and Trenches T-1 through T-13 as a result of past waste disposal practices. VOCs and SVOCs previously migrated downward through the vadose zone to the saturated zone.

In general, COCs may have migrated into the subsurface zones as dissolved constituents or as non-aqueous phase liquids (NAPLs). Along with this migration, residual contamination in the vadose zone and in the saturated zone likely occurred.

Characterization of contamination present in the subsurface soil source has not been completed. However, the presence of PCE above OU2 remediation target levels has been confirmed in the vicinity of Trench T-3.

PCE is essentially immiscible in water. However, PCE migration could have occurred by several mechanisms. The migration could have occurred directly if a sufficient amount (pool) of PCE existed to overcome capillary pressures; by diffusion; or by dissolution in another, more mobile NAPL. If the latter case were the main mechanism for downward PCE migration, one would also expect significant concentrations of the accompanying NAPL.

PCE has the ability to partition to the vapor phase via volatilization and the liquid phase via dissolution. Following migration into the subsurface, liquid-phase PCE will redistribute and come to rest either as disconnected ganglia and filaments (known as residual) or in the form of potentially mobile pools perched upon capillary barriers (Poulsen et al., 1992).

The ultimate penetration depth of PCE following a ground surface release depends on the volume released and the distance to the water table. Also important are the percentage of pore space occupied by the PCE and the irreducible water saturation, as well as the degree of lateral spreading exhibited by the migrating PCE.

The spatial distribution of the PCE migration paths depends on the bedding structure of the porous medium, with horizontal bedding promoting lateral spreading. The distribution of water content, the PCE fluid properties, and the manner in which PCE was introduced in the subsurface also affect the spatial distribution of PCE migration paths (Poulsen et al., 1992).

As previously stated in Section 2.3.1, analysis of SWMS measurements of soil moisture, matric potential, precipitation, and volume of collected freely flowing waters suggests that

23

preferential flow occurs under both unsaturated and saturated conditions. This preferential flow may have allowed the fluid transport of dissolved PCE from the subsurface soil medium to the groundwater during snowmelt and precipitation events.

#### **2.3.3.2 Intramedia Pathways**

Past and present intramedia transport has been and is primarily controlled by the flow of interstitial waters through preferential pathways within the subsurface soil source area, as described in Section 2.3.1. These transport mechanisms (e.g. colloidal, dissolution) are contaminant specific.

#### **2.3.4 Residual Subsurface Soil Contamination**

The intermedia pathway of residual subsurface soil contaminant migration from the Northeast trenches is the transport of contaminants from subsurface soil to groundwater. COCs in groundwater suggest that residual contamination in the vadose zone or saturated zone beneath the Northeast trenches may persist and act as a secondary source of contamination to groundwater. Intermedia and intramedia transport of PCE in the subsurface soil residual area will behave as described in Section 2.3.3, above.

#### **2.3.5 Upper Hydrostratigraphic Unit Groundwater Contamination**

##### **2.3.5.1 Intermedia Pathways**

The primary intermedia pathways affecting groundwater or affected by groundwater include the transport of contaminants from surface soils to groundwater, transport of contaminants from subsurface soils to groundwater, and the discharge of groundwater at seep or surface water locations. Transport of surface soil contaminants, i.e. Pu-239+240, was addressed in Section 2.3.1. Transport and fate of COCs in subsurface soils is described in Section 2.3.3. Discharge of contaminants at seep and surface water locations occurs where groundwater exits the UHSU in response to hydraulic gradients or where the UHSU is truncated along the OU2 hillsides.

NAPLs movement through subsurface soils may have been relatively rapid, especially if the soils were dry and the quantity of NAPLs was large. Fractures or macropores in the subsurface soils could have facilitated movement of NAPLs to groundwater. The fluid migration likely resulted in residual contamination in the vadose zone and possibly the underlying saturated zone. Dissolved-phase contaminants not held in the vadose zone ultimately reach the saturated zone where they mix with groundwater in the saturated groundwater system. NAPLs have been observed in Trench T-3 (DOE, 1995b) and are suspected in other OU2 contaminant disposal areas.

A NAPLs source in the subsurface soils can result in multiple incidents of dissolved contaminant releases to groundwater during percolation of precipitation and recharge to

groundwater. Residual NAPLs in subsurface soils can act as a long-term contaminant source to groundwater and greatly increase the time period of remediation.

### 2.3.5.2 Intramedia Pathways

The primary intramedia pathways include the transport of dissolved contaminants in groundwater present in both the Rocky Flats Alluvium and associated unconsolidated geologic materials and the No. 1 Sandstone, and dissolved contaminant transport between these water-bearing strata. Contaminant sources within the saturated UHSU include residual DNAPL globules and ganglia in the water-bearing zone pore space and possibly DNAPLs pooled on low-hydraulic-conductivity zones that serve as capillary barriers within the UHSU or stratigraphically-trapped on top of the Lower Hydrostratigraphic Unit (LHSU). PCE or other chlorinated solvents may also be dissolved in light non-aqueous phase liquid (LNAPL) pools that remain in the groundwater capillary fringe. Over time, these denser solvents may leach from the LNAPL pools into the groundwater in the dissolved phase. Such DNAPL and LNAPL sources provide a long-term source of VOC contaminants to groundwater.

Once in groundwater, Pu-239+240 may migrate as particulate and dissolved fractions. Pu-239+240 has been reported to sorb to particulates, including colloids. Pu-239+240 activity observed in groundwater as a percentage of total sample activity is distributed primarily in the particulate (40 percent) and dissolved (53 percent) fractions. Although colloids comprise about 92 percent of the total particle concentration in the groundwater only about 6 percent of the total plutonium activity is associated with colloidal particles; while 94 percent is associated with particulates. Pu-239+240 thus appears to be very particle-reactive and to also exhibit significant dissolved phase association (Harnish et al., no date).

Groundwater contamination in the saturated UHSU beneath the 903 Pad flows to the northeast along the medial paleoscur. Contaminant flow also occurs to the south-southeast towards Trench T-2 during the spring high water period. During low water periods, groundwater flow continues to the northeast along the medial paleoscur, but flow to the south-southeast becomes intermittent as water levels decrease. The predominant contaminants present in plumes emanating from the 9033 Pad Area are VOCs. VOC contaminants are found in groundwater in saturated portions of the Rocky Flats Alluvium, and colluvium, and have migrated vertically to the underlying No. 1 Sandstone west of the 903 Pad and in the area of the Northeast Trenches. Groundwater contaminants from the 903 Pad may extend to the Southeast Trenches area at low concentrations. Contaminated groundwater from the UHSU discharges at seeps near Trench T-2 and along the north-facing hillslope of South Walnut Creek.

### 3.0 CORRECTIVE/REMEDIAL ACTION OBJECTIVES

The C/RAOs consist of media-specific goals for protecting human health and the environment. Remediation may practice protectiveness through reducing exposure, such as capping an area or limiting access, or by reducing contaminant level, mobility, or toxicity. The C/RAOs were originally developed in Technical Memorandum No. 1 (DOE, 1995a). In response to regulatory comment, they have been revised as follows:

- Remediate contaminated surface and subsurface soils to non-zero chemical-specific ARARs or to-be-considered (TBC) values, as appropriate.
- In the absence of ARARs/TBCs, remediate contaminated surface and subsurface soils so that they are within an acceptable risk range (excess cancer risk greater than  $10^{-4}$  to  $10^{-6}$  or a hazard index of greater than one for noncarcinogens) considering the reasonable maximum exposure scenario.
- Remediate subsurface soils to levels which will ensure protection of groundwater as prescribed by ARARs/TBCs identified for groundwater considering site-specific subsurface soil/groundwater interactions. (Colorado State groundwater ARARs have been identified for OU2 based on the current groundwater use classification at the RFETS. If the use classification is changed in the future, new ARARs will be identified based on the new classification).
- Remediate groundwater to non-zero chemical-specific ARARs/TBCs, as appropriate.
- In the absence of ARARs/TBCs, remediate contaminated groundwater that would result in acceptable risk-based concentrations considering the reasonable maximum exposure scenario (total excess cancer risk of greater than  $10^{-4}$  to  $10^{-6}$  or a hazard index greater than one for noncarcinogens).

## **4.0 REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS**

For the purpose of this technical memorandum, the terms "technology" or "technology type" refer to general groupings of technologies potentially applicable to general response action (GRA). The term "process option" describes a specific process that is available for consideration within a particular technology type. A "representative process option" (RPO) is a single process option that is representative of similar process options within a given technology type. The RPOs are selected as the basis for developing and evaluating various remedial alternatives, which eliminates the need to conduct a comparative evaluation of multiple similar alternatives.

This section documents the identification and screening of remedial technologies and process options for the purpose of identifying RPOs that can be applied to developing remedial alternatives. The identification and screening of technologies and process options was performed according to CERCLA guidance (EPA, 1988) which included:

- Establishing media-specific GRAs for OU2;
- Identifying potentially applicable remedial technologies and process options for each contaminated medium;
- Screening the identified remedial technologies and process options against specific criteria to eliminate technologies and process options that are not applicable to site-specific conditions or may not achieve the C/RAOs for the particular media; and
- Selecting RPOs to develop remedial alternatives.

The GRAs that were established for OU2 are discussed in Section 4.1. A discussion of procedures and resources used to identify potentially applicable remedial technologies and process options is presented in Section 4.2. The screening procedure, screening criteria, and results of screening are presented in Section 4.3. Descriptions of the remedial technologies and process options that were retained after the screening process are provided in Appendices A (Surface and Subsurface soil) and B (Groundwater). The selection of the RPOs used to develop remedial alternatives is discussed in Section 4.4.

### **4.1 Identification of General Response Actions**

GRAs are strategies that describe general actions that will satisfy the C/RAOs established for OU2. Media-specific GRAs were developed for each environmental medium exhibiting COCs at concentrations above the selected remediation target for OU2. The media for which GRAs were developed include surface soil, subsurface soil (including IHSS-specific source controls), and groundwater. Identified GRAs may be implemented individually or in combination with other GRAs to meet the C/RAOs. The GRAs identified for contaminated

media include no action, institutional controls, containment, *in situ* treatment, removal, and *ex situ* treatment. A general description of each GRA is provided below.

- No Action - Required by CERCLA as a benchmark for comparison against other remedial action alternatives. Implies that no direct action will be taken to alter the existing situation, other than short- and long-term monitoring of site conditions.
- Institutional Controls - Refers to controls based on legal and/or management policies which minimize public exposure to potential contaminants. Examples include legally restricting land use by zoning provisions or modification of deeds, and site access controls such as fencing.
- Containment - Consists of those actions which would minimize or prevent migration of contaminants by wind dispersion or storm water erosion mechanisms for surface soil, and by infiltration and vadose zone transport mechanisms for subsurface soil and the saturated zone.
- *In Situ* Treatment - In general, *in situ* treatment refers to treatment of contaminants in place. *In situ* treatment actions would remove, detoxify, and/or immobilize contaminants using chemical, thermal, physical, or biological technologies.
- Removal - Includes remedial actions such as soil/waste excavation and groundwater extraction which are used to remove and/or consolidate contaminated media. Also includes transportation and disposal of non-hazardous, hazardous, radioactive, and mixed wastes at permitted facilities such as a landfills, storage vaults, injection wells, or underground repositories.
- *Ex Situ* Treatment - This action is similar to *in situ* actions with the exception that the contaminated media are extracted or removed prior to treatment. *Ex situ* actions separate or concentrate, detoxify, or immobilize contaminants using chemical, thermal, physical, or biological technologies.

#### 4.2 Identification of Technologies and Process Options

A comprehensive list of remediation technologies and process options was developed for the RFETS as part of Task 3 of the CMS/FS (EG&G, 1994). Resources consulted to compile the comprehensive list of technologies (CLT) (ES, 1994) included:

- EPA and DOE guidance documents;
- Technical publications, journals, and proceedings;

- Computerized remediation and waste treatment databases, including EPA's Vendor Information System for Innovative Treatment Technologies (VISITT), Risk Reduction Environmental Laboratory (RREL) Treatability Database, and Alternative Treatment Technology Information Center (ATTIC); and
- Existing RFETS documents, including treatability studies and interim measures/interim remedial action (IM/IRA) reports.

Information provided in the CLT and additional EPA and DOE guidance documents was used to identify technologies and process options which are potentially applicable to remediate the contamination present in OU2. The specific COCs for each medium presented in Section 2.1 were used as the basis for establishing three media-specific contaminant groups:

- Surface soil contaminated with radionuclides;
- Subsurface soils (including subsurface soil source areas) contaminated with VOCs, SVOCs, metals, and radionuclides; and
- UHSU groundwater contaminated with radionuclides and VOCs.

The comprehensive technology list for each medium provided the initial starting point for the screening and evaluation of the remedial technologies and process options. The lists of technologies are grouped under surface soils, subsurface soils, and groundwater, and are presented later in this section.

#### **4.3 Screening of Technologies and Process Options**

The list of technologies and process options for each medium was screened against established criteria for implementability, effectiveness, and cost. The goal of the screening process was to eliminate those technologies and/or process options that obviously could not be implemented because of OU2 site-specific factors, thereby reducing the number of remedial technologies and process options for consideration in the development of remedial alternatives.

The screening process was applied in two stages. The first stage was an initial technology screen based on technical implementability. The second stage included an evaluation of effectiveness, institutional implementability, and cost. Process options were screened and evaluated under the assumption that they would be implemented as the primary remedial treatment process. Therefore, several process options were not retained after screening because they were only applicable as a secondary treatment or a component of a potential remedial alternative. The following subsections present the methods, criteria, and results of the screening of technologies and process options; a description of the remedial technologies and process options that passed the screening criteria; and a discussion regarding the selection of representative process options retained for the development and detailed analysis of remedial alternatives.

#### 4.3.1 Initial Technology Screen - Technical Implementability

The initial technology screen is a fatal-flaw analysis based solely on technical implementability. This stage of screening required the review of site characteristics and specific information for each process option to identify any factor that would prevent the technology or process option from being implemented at OU2 for a specified contaminated environmental medium. Some factors affecting technical implementability that were considered during the fatal-flaw analysis were:

- Characteristic properties of contaminants;
- COC concentrations;
- Water table depth;
- Depth to bedrock;
- Horizontal and vertical extent of contamination;
- Hydrogeologic characterization; and
- Surface topography.

If any factor or combination of factors that would prevent a process option from being implemented was identified, that process option was eliminated from further consideration and the reason was documented. The initial technology screening process eliminated subsequent development of more detailed information for those technologies and process options that were determined to be obviously inadequate.

The results of the initial technology screen for surface soils are presented in Figure 4.1. This figure illustrates the relationship between surface soil GRAs, remedial technologies, and process options. Process option descriptions and screening comments are also presented. Shaded entries represent those technologies and process options that were eliminated during the initial technology screen.

Five surface soil technologies were removed from further consideration (Figure 4.1) based on the results of the initial technology screen. Three containment technologies (surface controls, groundwater controls, and vertical barriers), one *in situ* technology (chemical/physical), and one *ex situ* technology (thermal) were removed because associated process options were not applicable to the thin horizon of surface soils and/or could not be justified as a primary treatment process without inclusion of other process options. In addition, numerous process options were removed from consideration from the retained technologies for the reasons specified in the screening comments column.

Results of the initial technology screen for subsurface soils are presented in Figure 4.2. Surface controls and groundwater controls were eliminated as containment technologies because associated process options are not appropriate as primary treatment options by themselves and do not warrant further consideration in the feasibility study (FS). *Ex situ* biological treatment was eliminated as a technology type because associated process options are not practical for the volume of contaminated material or appropriate for the treatment of radionuclides. Thirteen other process options were eliminated for the reasons specified in the screening comments.

Results of the initial technology screen for groundwater are presented in Figure 4.3. Storage of contaminated groundwater was eliminated from further evaluation because this is not a long-term solution. *In situ* solidification/stabilization technologies were eliminated for the reasons identified in the screening comments column. It is assumed that any *ex situ* groundwater treatment performed will be conducted at the existing onsite water treatment plant. Therefore, all of the *ex situ* process options were eliminated except for the onsite water treatment plant. Twelve other process options were eliminated for the reasons specified in the screening comments.

Descriptions of remedial technologies and process options for soils (surface and subsurface) and groundwater that passed the initial technical implementability screen are presented in Appendices A and B, respectively.

#### 4.3.2 Technology Evaluation

The second stage of screening included an evaluation of effectiveness, institutional implementability, and relative cost. The evaluation of effectiveness was deemed to be the most important criterion in the technology evaluation stage. Specific remedial technologies and process options were evaluated on their effectiveness relative to other technologies or process options within the same technology type. The evaluation of effectiveness was based primarily on:

- The potential effectiveness of process options in handling the estimated areas or volumes of media and meeting the preliminary remediation goals (PRGs) and other C/RAOs;
- The potential impacts to worker safety, human health, and the environment during the construction and implementation phase; and
- The degree to which the processes are proven and reliable with respect to the contaminants and conditions at the site.

The evaluation of institutional implementability included consideration of:

- The ability to obtain the necessary permits for onsite and offsite actions;

- The availability of treatment, storage, and disposal services; and
- The availability of necessary equipment and skilled workers to implement the technology.

Because of the limited information on some of the innovative technologies, it was not always possible to evaluate these technologies at the same level of detail as the demonstrated and traditional remedial technologies and process options. Typically, innovative remedial technologies were judged to be institutionally implementable and were retained for further evaluation either as a "selected" process option or as "represented" by another similar process option within the corresponding technology type. Figure 4.4 presents the results of the technology evaluation for surface soil. All of the process options for surface soil were retained for further evaluation.

Figure 4.5 presents the results of the technology evaluation for subsurface soil. *In situ* biological treatment is not expected to meet C/RAOs for the subsurface COCs, but has been retained as an applicable technology to treat non-halogenated petroleum hydrocarbon in the source areas, if necessary. *In situ* pneumatic fracturing, electrokinetics, and electroacoustical soil decontamination were eliminated because they will not likely be effective at OU2. Four *ex situ* process options were also eliminated because they are not effective for treatment of the COCs or are difficult to implement.

Figure 4.6 presents the results of the technology evaluation for groundwater. Sheet piling was eliminated from further evaluation because it will be very difficult to implement at OU2. The multi-layer cap was also eliminated due to its high capital cost. All of the remaining process options were retained for further evaluation.

#### 4.4 Representative Process Options

All remedial technologies and process options that met the criteria for the initial technology screen and technology evaluation are presented as unshaded entries in Figures 4.4 through 4.6. RPOs were selected from retained process options for given technology types based on engineering judgement. Innovative technologies were only selected as RPOs if the literature documented that they would provide better treatment, fewer or lower adverse effects, and/or lower costs than more established process options. The ability of the innovative technology or process option to be implemented within a realistic timeframe was also taken into consideration.

The goal of the last screening step was to select one or two process options to represent each retained technology type. The selected RPOs for OU2 surface soils, subsurface soils, and groundwaters are presented in Tables 4.1 through 4.3, respectively. These tables also provide the GRAs and remedial technology types for each of the selected RPOs. For surface soil, 14 RPOs were selected (see Table 4.1). For subsurface soil, 21 RPOs were selected (see Table 4.2), and 17 RPOs were selected for groundwater (see Table 4.3). Further evaluation of the

selected RPOs is presented in Section 5.0 of this document. This additional process option analysis allowed for development and evaluation of distinct remedial alternatives.

## **5.0 POTENTIAL REMEDIAL ALTERNATIVES**

This section develops the remedial alternatives for the five remediation areas. This action is consistent with the IAG statement of work, which states: "The range of alternatives shall include, at a minimum: options to reduce the toxicity, mobility, or volume of wastes, but which vary in the types of treatment, the amount of wastes treated and the manner in which long-term residuals or untreated wastes are managed; options involving containment with little or no treatment; options involving both treatment and containment, and a no action alternative."

The remedial alternatives involving treatment and/or containment were assembled using combinations of the RPOs presented in Section 4.4 of this document. The RPOs and other suitable process options of the same technology types will be evaluated in depth during the detailed analysis of alternatives (DAA) and presented in the CMS/FS report. Because this section includes a reasonable range of alternatives, an initial screening of alternatives prior to the DAA will not be conducted. All remedial alternatives will be evaluated in detail during the DAA. Descriptions of the remedial alternatives are presented in the following subsections.

### **5.1 OU2 Surface Soils Source Alternatives**

Seven remedial alternatives for the OU2 surface soil sources were developed. These alternatives are designed to address remediation of Pu-239+240 contamination. Alternative concept diagrams are presented in Figures 5.1 through 5.3. General descriptions of each alternative are presented in the following sections.

Assumptions and considerations used during the assembly of alternatives for surface soil sources include:

- Disposal will be performed at an onsite or offsite treatment, storage, or disposal (TSD) facility such as Envirocare, Inc. or the Nevada Test Site (NTS); and
- Air sampling and radiological monitoring will continue under existing or modified programs to monitor for possible migration at concentrations above the remediation target level.

#### **5.1.1 GRA - No Further Action**

##### **Alternative 1: No Further Action with Long-Term Monitoring**

The no further action alternative consists of long-term monitoring for the surface soil source (Figure 5.1). No additional remedial activities or institutional controls will be implemented for this alternative.

The long-term radiological monitoring of surface soil and airborne dust would be performed to evaluate potential contaminant migration at levels above the OU2 remediation target level. If monitoring detects migration of contaminants above the selected OU2

remediation target for plutonium, a contingency plan would be implemented. The plan would evaluate the risks associated with the contamination and potential strategies to address the migrating contaminants that pose a threat to human health or the environment. The contingency plan may include implementation of one or any combination of the other surface soil alternatives presented below. Long-term surface soil and air monitoring would be conducted until the COC concentrations in the surface soils are consistently measured below the established OU2 remediation target.

This alternative does not meet C/RAOs. It is included only as a baseline for comparison with other alternatives.

### **5.1.2 GRA - Institutional Controls**

#### **Alternative 2: Deed Restrictions and General Access Restrictions**

Alternative 2 includes deed restrictions, site access restrictions, and long-term radiological monitoring of the surface soils and airborne dust. The deed restrictions would be implemented to legally restrict use of the contaminated areas within the site. Installation of fencing around the contaminated areas (Figure 5.1) and long-term security of the site would be implemented, as necessary, to limit access.

Similar to the no further action alternative, the institutional controls alternative includes long-term air sampling and radiological monitoring of surface soils to evaluate potential contaminant migration at unacceptable levels. A contingency plan would be developed to address risks associated with contaminant migration. The contingency plan may include implementation of one or any combination of the other surface soil alternatives presented below. Long-term monitoring would be conducted until the plutonium concentration is consistently measured below the selected remediation target.

### **5.1.3 GRA - Containment**

#### **Alternative 3: Cap in Place**

Alternative 3 includes an engineered cover (cap) that would be placed over the areas with surface soil contamination above the selected remediation target (Figure 5.1). The cap and the site terrain would be graded and seeded. Installation of fencing around the contaminated areas (Figure 5.1) and long-term security of the site would be implemented to limit access. Deed restrictions, security, and fencing would be installed, as necessary, to limit access to the site. Long-term radiological air monitoring of the site would also be performed. A contingency plan would be developed to address risks associated with contaminant migration.

The cap would be designed to decrease contaminant mobility by reducing air and surface water dispersion of surface soils and by reducing infiltration of surface water. Construction of the cap and site grading would direct surface water runoff away from the affected areas. The cap would include an asphalt cover, or an engineered cap to reduce erosion from wind and surface water.

In addition to construction of a cap, fencing around the site would be installed and site security would be implemented to limit access to the affected areas. Long-term air monitoring of the site would be performed to monitor for potential contaminant migration above the OU2 remediation target level through airborne dust.

This alternative would reduce contaminant migration to air, surface water, and groundwater. It would also reduce the potential for exposure to concentrations of plutonium greater than the selected remediation target.

#### 5.1.4 GRA - *In Situ* Treatment

##### Alternative 4: *In Situ* Stabilization/Solidification

Alternative 4 includes *in situ* stabilization/solidification of surface soils. It would reduce the mobility of the contaminants by reducing the potential for these contaminants to migrate as dust, become entrained with surface water runoff, or infiltrate further into subsurface soils (Figure 5.2). The surface soils would be mixed in-place with stabilization/solidification agents to produce a treated matrix that is resistant to both physical and chemical degradation. If long-term monitoring detected migrating contamination above the OU2 remediation target level, a contingency plan would be implemented.

Stabilization involves mixing the soil with a stabilization agent which chemically converts the contaminant into a less soluble and/or less toxic form. Solidification entails mixing the soil with a solidification agent that produces a leach-resistant, physically durable, solid product. The stabilization and solidification processes usually result in a volume increase of the contaminated matrix due to the addition of treatment agents. Treatment agents that could potentially be used for the source surface soil include:

- Cements (masonry, Portland, gypsum, or polymeric);
- Lime/pozzolan mixtures (lime/fly ash, or lime/blast furnace slag); and
- Encapsulation binders (bitumen, thermoplastic polymers, or catalyzed polymers).

*In situ* stabilization/solidification would be performed using a variety of common types of mixing equipment. For surface soils, backhoe-mounted equipment such as mixing injectors, rippers, disk harrows, and plows can be used. Depending on the site conditions during the remedial activities, as determined by monitoring, dust suppression measures and/or dust collection equipment may be required.

Following *in situ* stabilization or solidification, the treated areas may be graded, covered with clean topsoil, and seeded to provide a vegetative cover. These measures would be implemented to reduce the infiltration of surface water into the treated areas, increase evapotranspiration, and reduce the potential for erosion and exposure to the treated soil.

Long-term radiological air monitoring would be required to ensure that airborne particulates from the site are not above acceptable contaminant levels. Fencing would be installed around the affected areas and site security would be implemented to limit potential contact with the treated soils.

The stabilization/solidification would reduce the toxicity and/or mobility of the radioactive contamination. The fencing and site security components of this alternative would reduce the potential for exposure to the treated soils.

#### **5.1.5 GRA - Removal**

##### **Alternative 5: Excavation and Disposal**

Alternative 5 would include the removal of all contaminated surface soil that exceeds the selected remediation target for plutonium, and subsequent onsite or offsite disposal (Figure 5.2). The excavated soil would be analyzed to determine the appropriate disposal requirements. The disturbed areas would be backfilled with clean soil and reseeded to provide a vegetative cover. During and after the excavation activities, surface soil sampling would be performed to ensure that all of the contamination above the OU2 remediation target has been removed. No long-term radiological monitoring would be required once it had been demonstrated that remediation target levels were achieved.

Excavation of surface soils would be performed using conventional earthmoving equipment such as backhoes, bulldozers, and graders. Depending on the site conditions during the remedial activities, dust suppression or dust collection measures will be required. Monitoring of airborne particulates during excavation would establish the requirements for dust control measures. Following excavation, the contaminated soils would be containerized utilizing drums, crates, and/or rolloff boxes and transported to the appropriate disposal facility by a conveyor system, trucks, and/or railcars.

The excavated soils would be disposed either onsite at the RFETS or at an appropriate offsite TSD facility. Analytical testing of the excavated soils would be required to ensure compliance with disposal requirements.

Clean fill from either an onsite or an offsite borrow source would be used as backfill for the excavations. Seeding of the affected areas may be performed to establish a vegetative cover. The benefits of a vegetative cover would be similar to those described in Section 5.1.4.

Removal of the contaminated soils and disposal at a permitted facility would eliminate potential onsite exposure to plutonium above the selected remediation target.

### **5.1.6 GRA - *Ex Situ* Treatment**

#### **Alternative 6: Excavation and Soil Washing**

Alternative 6 encompasses the excavation of contaminated surface soils, and transportation to an onsite facility for treatment by soil washing methods (Figure 5.3). After soil washing, the clean fraction of the treated soil would be used as backfill for the excavations. The contaminated fraction would be transported to an onsite or offsite disposal facility. After backfilling of the excavations, the affected areas may be seeded to establish a vegetative cover. During and after the excavation activities, surface soil sampling would be performed to ensure that all of the contamination above the selected remediation target has been removed. No long-term radiological monitoring would be required once it had demonstrated that remediation target levels were achieved.

Soil washing is a treatment process in which particle sizing and separation techniques are used to separate relatively contaminated soil fractions (typically the finer-grained fraction) from relatively clean, coarser fractions. Excavated soils are first wet-scrubbed and sized to separate coarse-sized soil fractions from fines. The coarse-size soils are returned to the excavation, and the finer soils are subjected to attrition scrubbing with surfactants, chelating agents, or other conditioning agents to further concentrate the contaminants. Following treatment by soil washing, the clean fraction of the soil, as determined by a radiological survey, would be returned to the site for use as backfill in the excavations. The contaminated fraction and the treatment residuals (e.g., washing solutions) would either be treated further and/or disposed at an appropriate onsite or offsite disposal facility.

After backfilling of the excavations, the affected areas would be seeded to provide a vegetative cover. Additional clean fill may be required to replace the soil lost as fines during washing activities. The benefits of a vegetative cover would be similar to those described in Section 5.1.4.

Removal of the contaminated soils from the site would eliminate potential exposure to plutonium contaminated soil above the selected remediation target.

### **5.1.7. GRA - *Ex Situ* Treatment**

#### **Alternative 7: Excavation, *Ex Situ* Stabilization, and Return to Excavation**

Alternative 7 would include excavation of the contaminated surface soils and onsite stabilization treatment (Figure 5.3). After treatment, stabilized soils that meet radiological requirements would be used onsite as backfill for the excavations. Soils not meeting the requirements would be disposed at an appropriate TSD facility. After backfilling the excavations with the treated soils, the affected areas may be seeded to allow for establishment of a vegetative cover. No long-term radiological monitoring would be required once it had been demonstrated that remediation target levels were achieved.

The excavation activities for this alternative would be the same as those described in Section 5.1.5 (Alternative 5). Sampling and monitoring activities during the excavation would also be the same as those described for Alternative 5. Containerization and transportation of the excavated soil to an onsite treatment facility would be required.

Treatment of the excavated soils would involve mixing with a stabilization agent which would chemically convert the contaminant into a less soluble and/or less toxic form. This process would result in a volume increase of the contaminated matrix. Treatment agents that could potentially be used are presented in Section 5.1.4. This alternative would require installation of a temporary or permanent onsite treatment facility capable of performing stabilization. When soils have been stabilized they will be returned to the excavated area, covered with topsoil, and revegetated, similar to Alternative 6.

The stabilization would reduce the toxicity and/or mobility of the contaminants contained within the soil matrix. The fixation of radionuclides in the soil matrix would eliminate potential onsite exposure to plutonium-contaminated soil above the selected remediation target. Institutional controls would be added as required.

## **5.2 OU2 Subsurface Soils Source Alternatives**

Eleven potential remedial alternatives for the OU2 subsurface soil sources were developed. The alternatives are illustrated in Figures 5.4 through 5.8 as concept flow diagrams. These alternatives are further described and evaluated in EE/CAs for subsurface soil sources.

Assumptions used during the assembly of remedial alternatives for subsurface soil sources include:

- Pyrophoric uranium chips exist in at least some of the buried drums in Trench T-1;
- Some drums buried at the site may have leaked, resulting in the release of contaminants to the subsurface soils in the trench; and
- Heavy metals, organics, and radionuclides are assumed to be potentially present in addition to the risk-based COCs.

### **5.2.1 GRA - No Further Action**

#### **Alternative 1: No Further Action with Long-Term Monitoring**

The no further action alternative includes intrinsic remediation and long-term monitoring for the subsurface soil source (Figure 5.4). No additional remedial activities or institutional controls would be implemented for this alternative.

The monitoring component of the no further action alternative would consist of periodic soil sampling to monitor natural contaminant degradation and groundwater monitoring to evaluate potential contaminant migration. If monitoring detects migration of contaminants above the OU2 remediation target, a contingency plan would be implemented to evaluate the risks associated with the contamination and develop potential strategies to address the migrating contaminants that pose a threat to human health or the environment. The contingency plan may include implementation of one or any combination of the other subsurface soil source alternatives as presented below. The monitoring program would be conducted until the COC concentrations in the subsurface soils and groundwater are below the OU2 remediation target.

This alternative does not meet C/RAOs. It is included only as a baseline for comparison with other alternatives.

### **5.2.2 GRA - Institutional Controls**

#### **Alternative 2: Deed Restrictions and General Access Restrictions**

Alternative 2 includes deed restrictions, general access restrictions, and long-term monitoring of the subsurface soils and groundwater. The deed restrictions would be implemented to legally restrict use of the contaminated areas within the site. No construction, excavation, or other intrusive activities would be allowed, reducing potential exposure to the contaminants. Installation of fencing around the contaminated areas and long-term security of the site would be implemented to limit access.

The long-term monitoring would be similar to that described for the no further action alternative. A contingency plan would be developed and monitoring would continue until the COC concentrations in the subsurface soils and groundwater are below the OU2 remediation target.

### **5.2.3 GRA - Containment**

#### **Alternative 3: Cap in Place**

Alternative 3 includes installation of an engineered cover (cap) over the areas where subsurface soil contamination exceeds selected remediation targets. Grading of the cap and the site terrain would be performed. Deed restrictions and general access restrictions would be implemented to limit potential exposure to the contaminated soils. Long-term monitoring of the subsurface soils and groundwater would also be performed for this alternative.

The cap would be designed and constructed to decrease contaminant mobility by reducing infiltration of surface water into the contaminated areas. Grading of the cap and site terrain would direct surface water runoff away from the affected areas. The cap would include a vegetative cover to reduce erosion from wind and surface water and increase evapotranspiration. The cap would not reduce migration of contaminants through the groundwater exposure pathway.

The deed restrictions and general access restrictions would be consistent with Alternative 2. The long-term monitoring would be similar to that described for the no further action

alternative. A contingency plan would be developed, and if necessary, monitoring would continue the COC concentrations in the subsurface soils and groundwater are below the OU2 remediation target. Groundwater would be monitored to measure any contaminant contribution from the subsurface soil source.

The capping and the institutional controls implemented for this alternative would reduce potential exposures to the subsurface soil sources, and minimize downward leaching of contaminants to groundwater.

#### **5.2.4 GRA - Containment**

##### **Alternative 4: Cap in Place and Install Vertical Barrier**

Alternative 4 includes installation of an engineered cover (cap) over the subsurface soil source areas, and installation of a vertical barrier around the contaminated areas (Figure 5.5). This alternative is the same as Alternative 3 with the addition of a vertical barrier. The vertical barrier could consist of a slurry wall or synthetic membrane wall. The appropriate type of vertical barrier for the site conditions will be determined in the DAA. The vertical barrier, which would be tied into the engineered cover system and competent bedrock, would reduce the mobility of contaminants from the subsurface soil sources by reducing the flow of groundwater through the area. As with Alternative 3, grading of the cap and surface terrain would reduce the mobility of the contaminants by reducing infiltration of surface water into the contaminated areas. The containment system would be designed to be passive, with no significant long-term maintenance requirements. No dewatering or active groundwater collection/treatment system within the contaminated areas would be installed.

#### **5.2.5 GRA - *In Situ* Treatment**

##### **Alternative 5 : Thermally Enhanced Soil Vapor Extraction (SVE), Enhanced Bioremediation, and Cap**

Alternative 5 for the subsurface soil source (Figure 5.5) includes thermally enhanced soil vapor extraction (TSVE) to treat the VOCs and bioremediation for treatment of SVOCs. An engineered cover would be installed to reduce infiltration of surface water and contain the other contaminants (radionuclide and metals) remaining in the subsurface soils. Similar to Alternative 3, this alternative includes deed and access restrictions and long-term monitoring of subsurface soils and groundwater.

The TSVE system utilizes heat and vacuum pressure to volatilize and remove organic contaminants. Offgas from the TSVE would be treated using granular activated carbon or an equivalent treatment system to remove volatilized organics. The sorbed collection media would require treatment, recycle, or disposal. Potential offgas treatment alternatives will be evaluated in the DAA.

Enhanced bioremediation would be implemented to degrade SVOCs in the subsurface soil. This will involve supplying oxygen, moisture, and/or nutrients to the contaminated soils

to increase the naturally occurring degradation of contaminants. As with Alternative 3, the cap would reduce potential contaminant mobility, exposures, and infiltration of surface water, and prevent human and environmental contact with source media.

The deed restrictions and general access restrictions would be consistent with Alternative 2. The long-term monitoring would be similar the no further action alternative. A contingency plan would be developed and monitoring would continue until the COC concentrations in the subsurface soils and groundwater are below the OU2 remediation target. Groundwater monitoring would be performed to measure any contaminant contribution from the subsurface soil source.

The TSVE and the enhanced bioremediation included in this alternative would significantly reduce the concentrations of VOCs and SVOCs in the subsurface soil source. The capping and the institutional controls implemented for this alternative would reduce potential exposures to the subsurface soil sources.

#### **5.2.6 GRA - *In Situ* Treatment**

##### **Alternative 6: TSVE, Enhanced Bioremediation, *In Situ* Stabilization, and Cap**

Alternative 6 includes all of the technologies presented in Alternative 5, including TSVE, enhanced bioremediation, and capping with the addition of *in situ* stabilization of the subsurface soils. Cap and site grading would be performed and deed and general access restrictions would be implemented. As with Alternative 5, long-term monitoring of the subsurface soils and groundwater would be performed.

*In situ* stabilization would be used to reduce the toxicity and mobility of the metal and radionuclide contaminants by producing a treated medium that is resistant to both physical and chemical degradation, as described in Section 5.1.4. Stabilization would be performed after the completion of TSVE and enhanced bioremediation. Following the stabilization of the subgrade soils, the affected areas would be capped with an engineered cover, as described in Section 5.2.4.

Implementation of this alternative would result in a significant reduction of potential exposure to contaminants above selected remediation targets. The *in situ* treatment of the contaminants would result in a reduction in the toxicity and mobility of the COCs. Capping would reduce the potential for exposure to the remaining contaminants and would minimize infiltration.

#### **5.2.7 GRA - *In Situ* Treatment**

##### **Alternative 7: Free Liquid Removal, *In Situ* Stabilization, and Cap**

Alternative 7 for the subsurface soil source (Figure 5.6) includes free liquid removal, *in situ* stabilization and capping of the affected areas. Also included with this alternative are deed and general access restrictions and long-term monitoring.

Free liquid removal would be accomplished by installation of temporary extraction wells and/or piping into the subsurface soils. Conventional pumping techniques would be used to remove any free liquids from the subsurface soils. The removed liquids would be subject to analytical testing to evaluate concentrations. If liquids removed from the subsurface soils meet the waste acceptance criteria (WAC), they would be transported to an onsite disposal facility or offsite to an appropriate TSD facility for treatment and/or disposal.

Following free liquid removal, stabilization and capping would be implemented, as presented for Alternative 6. As with the no further action alternative, long-term monitoring of the subsurface soils and groundwater would be performed.

The free liquid removal and the stabilization would significantly reduce the mobility and toxicity of contaminants in the subsurface soils. The capping would reduce the mobility of contaminants and would also reduce the potential of exposure to the subsurface soils. The deed and general access restrictions would reduce the potential for exposure to the subsurface soils.

#### **5.2.8 GRA - *In Situ* Treatment**

##### **Alternative 8: *In Situ* Vitrification (with Pretreatment as Necessary)**

Alternative 8 for the subsurface soil source (Figure 5.7) includes *in situ* vitrification with pretreatment, as necessary. Also included in this alternative are the institutional controls, including deed and general access restrictions, and the long-term monitoring described for Alternative 2.

*In situ* vitrification utilizes heat generated between electrodes installed in the subsurface soils to melt the contaminated matrix. During the vitrification process, the inorganic wastes are transformed into a molten, vitreous mass that, when cooled, forms a glass-like matrix that is leach resistant and that does not need secondary containment. Offgas collection and treatment would be required to treat contaminants volatilized during the vitrification process. Offgas collection and treatment systems will be evaluated in the DAA.

The *in situ* vitrification process would result in reductions of toxicity and mobility of the contaminants. The deed and general access restrictions would reduce the potential for exposure to the subsurface soils.

#### **5.2.9 GRA - Removal**

##### **Alternative 9: Excavation and Disposal**

Alternative 9 for the subsurface soil source includes removal and disposal of the subsurface soil sources. The removed materials would be analyzed to determine the appropriate disposal requirements. The disturbed areas would be backfilled with clean soil and reseeded to provide a vegetative cover. During and after the removal activities, soil sampling would be performed to ensure that all of the contamination with concentrations above selected remediation

targets had been removed. Long-term monitoring may not be required once it was demonstrated that remediation target levels have been achieved.

After removal, the excavated wastes would be separated, containerized, and characterized for transport and disposal. The waste would be evaluated to determine disposal requirements. Depending on the contamination of the soil remaining in-place after excavation, further remedial activities may or may not be required. If required, remaining contamination would be controlled using technologies described in Alternatives 2 through 8 or 10 and 11.

Clean fill from either onsite or an offsite borrow source would be used as backfill for the excavations. Seeding of the affected areas would be performed to allow for establishment of a vegetative cover.

Removal of the subsurface soil sources would significantly reduce potential exposures to contaminants that exceed selected remediation targets. Backfilling of the excavations would reduce the potential for exposure to the remaining subsurface soil contaminants.

#### **5.2.10 GRA - *Ex Situ* Treatment**

##### **Alternative 10: Excavation, Organics Removal, and Soil Washing**

Alternative 10 is similar to Alternative 9 except that excavated soils would be treated aboveground using organics removal and soil washing technologies (Figure 5.8). During and after the removal activities, soil sampling would be performed to ensure that all of the contamination with concentrations above selected remediation targets was removed. Long-term monitoring may not be required once it is demonstrated that remediation target levels have been achieved.

After excavation and separation, drums and their contents will be repackaged as required and the soil will be treated. Excavated soil will be treated initially using organics removal technologies. After the soils are treated for organics, they will be treated using soil washing technologies as discussed in Section 5.1.6. Clean material and soil fractions resulting from soil washing will be returned to the site, graded, and revegetated. All wastes that are not suitable to be returned to the site will be analytically characterized to determine the appropriate disposal requirements and will be managed accordingly.

Removal of the subsurface soil sources would significantly reduce potential exposures to contaminants that exceed selected remediation targets. Backfilling of the excavations would reduce the potential for exposure to the remaining subsurface soil contaminants.

#### **5.2.11 GRA - *Ex Situ* Treatment**

##### **Alternative 11: Excavation, *Ex Situ* Stabilization, and Return to Excavation**

Alternative 11 is similar to Alternative 10 except that excavated soils would be treated aboveground using stabilization technologies (Figure 5.8). During and after the removal

activities, soil sampling would be performed to ensure that all contamination above selected remediation target levels was removed. Long-term monitoring may not be required once it is demonstrated that remediation target levels have been achieved.

After excavation and separation, drums and their contents would be repackaged as required and the soils would be treated. Stabilization would be used to reduce the mobility of the contaminants in the excavated subsurface soils by producing a treated medium that is resistant to both physical and chemical degradation as described in Section 5.1.4. The stabilized waste form will be analyzed for VOCs, SVOCs, toxicity characteristic leaching procedure (TCLP) and a radiological survey will be performed. If the wastes meet analytical requirements, they will be returned to the excavation, graded, and revegetated. Any wastes that do not meet the analytical requirements will be re-stabilized until the requirements are met or they will be disposed at an appropriate onsite or offsite TSD facility. Drummed wastes will be evaluated, and disposed at the appropriate TSD facility.

Removal of the subsurface soil sources would significantly reduce potential exposures to contaminants that exceed selected remediation targets. Backfilling of the excavations would reduce the potential for exposure to the remaining subsurface soil contaminants.

### **5.3 OU2 Surface Soils Residual Alternatives**

Seven remedial alternatives for the OU2 residual surface soil remediation area were developed to address Pu-239+240, contamination. These alternatives are illustrated in concept flow diagrams in Figures 5.9 through 5.11. The same assumptions and considerations presented under source area surface soils (Section 5.1) apply to this remediation area.

#### **5.3.1 GRA - No Further Action**

##### **Alternative 1: No Further Action with Long-Term Monitoring**

Alternative 1 consists of long-term monitoring for the surface soil residual (Figure 5.9). No additional remedial activities or institutional controls would be implemented for this alternative. The long-term monitoring of surface soil and airborne dust would be consistent with Alternative 1 for the surface soil source, as presented in Section 5.1.1. This alternative does not meet C/RAOs and is included only as a baseline for comparison with other alternatives.

#### **5.3.2 GRA - Institutional Controls**

##### **Alternative 2: Deed Restrictions and General Access Restrictions**

Alternative 2 includes deed restrictions, site access restrictions, and long-term radiological monitoring of surface soils and airborne dust (Figure 5.9). The components of this alternative are consistent with those presented for Alternative 2 for the surface soil source (Section 5.1.2).

### **5.3.3 GRA - Containment**

#### **Alternative 3: Vegetative Cover**

Alternative 3 involves placing a vegetative cover over surface soil contamination (Figure 5.9). This alternative also includes deed restrictions, site access restrictions, and long-term radiological monitoring of surface soils and airborne dust, as described in Section 5.1.2.

The vegetative cover would include a 6-inch-thick layer of organic soil capable of sustaining vegetation. The area would be seeded with plants and grasses native to the area to augment the native vegetative cover currently established.

Implementation of this alternative would reduce potential exposure to plutonium contamination above the selected remediation target. This alternative also reduces migration of surface soils in storm water runoff and as airborne dust.

### **5.3.4 GRA - Containment**

#### **Alternative 4: Cap in Place**

Alternative 4 includes an engineered cover that would be placed over surface soil contamination areas (Figure 5.10). As with Alternative 3, for surface soil source areas (Section 5.1.3), grading of the cap and the site terrain would be performed and security and fencing would be implemented to limit access to the site. Long-term air monitoring of the site would be performed.

This alternative would reduce contaminant migration via air, surface water, and groundwater. It would also reduce the potential for exposure to plutonium contamination that exceeds the selected remediation target.

### **5.3.5 GRA - *In Situ* Treatment**

#### **Alternative 5: *In Situ* Stabilization/Solidification**

Alternative 5 includes *in situ* stabilization/solidification of surface soil residuals (Figure 5.10). Deed and general access restrictions and long-term air monitoring would be implemented. This alternative is consistent with that for surface soil sources, as described in Section 5.1.4.

The stabilization/solidification would reduce the toxicity and/or mobility of the plutonium contamination in soil. This alternative would reduce the potential for exposure to the treated soils.

### **5.3.6 GRA - Removal**

#### **Alternative 6: Excavation and Disposal**

Alternative 6 includes excavating plutonium-contaminated surface soils that exceed the selected remediation target and disposal at an approved onsite or offsite TSD facility (Figure 5.10). The excavated areas would be regraded and seeded to provide a vegetative cover. No long-term radiological monitoring would be required because the contaminated soils would be removed from the site. The components of this alternative are consistent with those described in Section 5.1.5 for the surface soil sources. Removal of the contaminated soils and disposal at a permitted facility would eliminate potential exposure to plutonium-contaminated soil that exceeds the selected remediation target.

### **5.3.7 GRA - Ex Situ Treatment**

#### **Alternative 7: Excavation and Soil Washing**

Alternative 7 includes excavating plutonium-contaminated surface soils that exceed the selected remediation target, and treating the contaminated soil using soil washing technologies (Figure 5.11). Following the treatment by soil washing, the clean fraction of the soil would be returned to the site as backfill for the excavations. No long-term radiological monitoring would be required because the contaminated soils would be removed from the site and treated. The contaminated fraction and the treatment residuals would either be treated further and/or disposed at an appropriate onsite or offsite disposal facility. The components of this alternative are consistent with those described in Section 5.1.6 for the surface soil sources. Excavation and soil washing would eliminate potential exposure to plutonium contaminated soil that exceeds the selected remediation target.

## **5.4 OU2 Subsurface Soils Residuals Alternatives**

Two alternatives for subsurface soils residuals will be evaluated in the DAA. They include the no further action and the SVE alternatives. The no further action alternatives will be retained for comparison purposes only (Figure 5.12). Selection of SVE is based on the EPA guidance document, *Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with Volatile Organic Compounds in Soils* (EPA, 1993b).

The objective of the presumptive remedies initiative is to use the Superfund program's past experience to streamline site investigations and expedite selection of cleanup actions. Presumptive remedies are preferred technologies for common categories of sites, based on historical patterns of remedy selection and EPA's scientific and engineering evaluation of performance data on technology implementation. Over time, presumptive remedies are expected to ensure consistency in remedy selection and reduce the cost and time required to clean up similar types of sites. In addition, presumptive remedies are expected to be used at all appropriate sites except under unusual site-specific circumstances. SVE, thermal desorption, and incineration are the presumptive remedies for Superfund sites with VOC-contaminated soil, assuming the site characteristics meet certain criteria.

In general, the presumptive remedy alternative for subsurface soils residuals at OU2 would utilize SVE (ambient or thermally enhanced) to reduce VOC concentrations in subsurface soils. Soil vapor extraction wells, installed in the contaminated areas, would volatilize and remove the COCs. The extraction system may be thermally enhanced to increase the efficiency of the volatilization and removal system. This alternative is consistent with that for the subsurface soil source as described in Section 5.2.5, although no bioremediation or stabilization would be performed for the subsurface soil residual. This alternative would include long-term monitoring of the subsurface soils and groundwater. The *in situ* SVE would reduce the toxicity of contaminated soil and reduce the potential for exposure to PCE-contaminated soils that exceed the selected remediation target.

The *Feasibility Study Analysis for CERCLA Sites with Volatile Organic Compounds in Soil* (EPA, 1994) provides the basis for limiting the analysis of technologies and alternatives when applying the presumptive remedy approach. Information from the feasibility study performed by the EPA will be utilized in the DAA in developing recommendations for the remedial action plan.

### 5.5 Remediation Alternatives for OU2 Groundwater

Five alternatives are proposed to remediate contaminated UHSU groundwater beneath OU2. A description of each alternative is presented in Table 1.1. The alternatives include:

- No further action;
- Institutional controls;
- Containment with or without treatment of drainage;
- *In situ* treatment; and
- Extraction and *ex situ* treatment alternatives.

Concept diagrams of the candidate alternatives are provided in Figures 5.13 through 5.14. Proposed implementation of the alternatives is shown on Figures 5.15 through 5.17. Descriptions of onsite water treatment facilities and pertinent treatability testing programs are presented in Technical Memorandum No. 1 for OU2.

Assumptions and considerations used to develop the groundwater remediation alternatives include:

- Surface and subsurface soil sources have been removed and/or remediated;

- Groundwater within the UHSU can be remediated using individual alternatives or a combination of containment, collection and *in situ* or *ex situ* treatment alternatives;
- Existing RFETS onsite water treatment facilities have sufficient capacity, or if necessary, can be upgraded to process groundwater from OU2;
- Existing RFETS onsite water treatment facilities are designed, or can be upgraded, to treat all of the OU2 COCs to acceptable concentrations; and
- The acknowledged limitations of remediating DNAPL-contaminated groundwater to selected remediation targets are recognized and alternative remedial strategies may apply.

Potential difficulties and limitations inherent in remediating DNAPL-contaminated groundwater to federal and state cleanup levels are acknowledged and discussed in EPA's "*Guidance For Evaluating the Technical Impracticability of Ground-Water Restoration*" (EPA, 1993a) and "*Alternatives For Groundwater Cleanup*" (National Research Council, 1994). EPA (1993a) presents guidance for assessing the technical impracticability of groundwater remediation for certain site and contaminant conditions, and provides guidance for implementing remediation at these sites. Recognized conditions that may limit the practicability of groundwater remediation include complex stratigraphy, low hydraulic conductivity, presence of fractures, and the occurrence of DNAPLs. Although technical impracticability evaluations are typically conducted after a ROD or after remediation has been implemented, precedence exists for conducting technical impracticability evaluations during the CMS/FS. Evaluation of the technical impracticability for groundwater remediation at OU2 will be conducted as part of the DAA.

The natural shape of the medial paleoscouer and the geometry of the UHSU and surrounding low hydraulic conductivity bedrock lithologies provide a convenient mechanism for hydraulic control and/or collection of UHSU groundwater at OU2. Extraction wells can be positioned in areas where the hydraulic conductivity and saturated thickness of the UHSU are optimal to maximize groundwater production and areal drawdown. Collection trenches can be situated in areas where the medial paleoscouer narrows to maximize groundwater collection with the minimum amount of trench length.

The two primary geologic units of the UHSU that have the greatest areal distribution and exhibit the greatest saturated thickness at OU2 are the Rocky Flats Alluvium and the No. 1 Sandstone. These units appear to contain most of the groundwater at OU2. Because of the importance of these units in the conceptualization and design of any remedial alternative requiring groundwater extraction, injection, or control, discussions of their relevant geologic and hydraulic characteristics are described below.

**Rocky Flats Alluvium** - The Rocky Flats Alluvium is the most widely distributed, saturated, unconsolidated geologic unit underlying OU2. As illustrated in Figure 5.18, the thickest occurrence of the Rocky Flats Alluvium is found in the medial paleoscour where the saturated thickness is also greatest. Groundwater flow in the alluvium in the medial paleoscour is generally to the east-northeast at a gradient of 0.020 ft/ft as measured during March and May 1992. Because the Rocky Flats Alluvium is erosionally truncated to the north, east, and south within OU2, all alluvial groundwater is discharged to surface and subsurface seeps along the bounding hillslopes of the South Walnut Creek and Woman Creek drainage basins, except for alluvial groundwater that recharges the underlying consolidated bedrock units.

The horizontal hydraulic conductivity values of the Rocky Flats Alluvium range between  $5 \times 10^{-2}$  and  $4 \times 10^{-5}$  centimeters per second (cm/s) and has a geometric mean of  $6 \times 10^{-4}$  cm/s. Laboratory vertical hydraulic conductivity values range between  $1.3 \times 10^{-7}$  and  $1.2 \times 10^{-8}$  cm/s. These figures are from the Preliminary Draft OU2 Phase II RFI/RI Report. Because the hydraulic conductivity of the Rocky Flats Alluvium is moderately low, passive groundwater collection and extraction methods are most appropriate for this unit. The calculated average groundwater flow velocity is about 120 feet per year, assuming a hydraulic conductivity of  $6 \times 10^{-4}$  cm/s, an average hydraulic gradient of 0.020 ft/ft, and an assumed effective porosity of 10 percent. No measured values of effective porosity of the Rocky Flats Alluvium are known.

**Arapahoe Formation No. 1 Sandstone** - The No. 1 Sandstone is a fluvial sandstone channel deposit bounded by the surrounding bedrock strata that typically consist of claystone or siltstone or by the north-facing hillslopes of the South Walnut Creek drainage. The No. 1 Sandstone directly subcrops beneath the Rocky Flats Alluvium in some areas and is separated from the alluvium by bedrock claystone in other areas. Because the No. 1 Sandstone is erosionally truncated along the north, east, and south by the South Walnut Creek and Woman Creek drainages, no direct groundwater pathway exists within the sandstone from OU2 to offsite locations. Almost all sandstone groundwater at RFETS discharges to seeps at the surface.

The No. 1 Sandstone was deposited in channel-incised bedrock claystone of the Laramie Formation. Groundwater flow in the sandstone is controlled by the geometry of the sandstone unit and its interaction with the overlying saturated alluvium, and the South Walnut Creek and Woman Creek drainages. Groundwater flow in the No. 1 Sandstone is toward the northeast, and locally southeast near the Northeast Trenches. The hydraulic gradient ranges between 0.028 ft/ft and 0.1 ft/ft. Measured vertical hydraulic gradients between the Rocky Flats Alluvium and No. 1 Sandstone range between 0.003 ft/ft and 0.019 ft/ft, generally suggesting that the units are hydraulically connected.

The No. 1 Sandstone exhibits moderately low horizontal hydraulic conductivity, with measured values ranging between  $3 \times 10^{-3}$  and  $2 \times 10^{-4}$  cm/s and a geometric mean of  $7 \times 10^{-4}$  cm/s. Vertical hydraulic conductivity values range between  $1.1 \times 10^{-4}$  and  $3.1 \times 10^{-9}$  cm/s. These figures are from the Preliminary Draft OU2 Phase II RFI/RI Report. The wide range of vertical hydraulic conductivity values suggests that horizontal layering may be an important hydraulic control in the No. 1 Sandstone. As with the Rocky Flats Alluvium, passive

groundwater collection and extraction methods are most applicable to this formation. However, in areas where the No. 1 Sandstone exhibits greater hydraulic conductivities and large saturated thicknesses, groundwater may be extracted using pumping wells. Calculated groundwater flow velocity values for the No. 1 Sandstone range between 200 and 730 feet per year. These velocities were calculated using a hydraulic conductivity of  $7 \times 10^{-4}$  cm/s, hydraulic gradients ranging between 0.028 ft/ft and 0.1 ft/ft, and an assumed effective porosity of 10 percent.

#### **5.5.1 GRA - No Further Action**

##### **Alternative 1: Intrinsic Remediation**

The no further action alternative (Figure 5.13) provides a baseline for comparison against other alternatives. Long-term groundwater monitoring will be conducted as part of this alternative and an evaluation of natural contaminant degradation (intrinsic remediation) and contaminant migration will be assessed. Intrinsic remediation is the action of natural processes, such as dilution, volatilization, biodegradation, adsorption, and chemical reactions, to reduce contaminant concentrations to acceptable levels. Consideration of intrinsic remediation requires monitoring and predictive modeling of contaminant migration and degradation rates to determine the feasibility of meeting C/RAOs.

Long-term monitoring will be conducted until groundwater no longer poses a threat to human health or the environment. If intrinsic remediation is not effective and contaminant migration occurs, a contingency plan will be implemented to evaluate the associated risks and to develop strategies to address contaminant migration that poses a threat to human health or the environment. The contingency plan may include implementation of one or any combination of Alternatives 2 through 5.

Alternative 1 provides no control of exposure to contaminated groundwater. However, risk reduction may be achieved through intrinsic remediation.

#### **5.5.2 GRA - Institutional Controls**

##### **Alternative 2: Deed Restrictions and Access Restrictions**

Alternative 2, institutional controls, includes limiting use of contaminated groundwater through property deed restrictions and minimizing access to contaminated groundwater and groundwater discharge areas (seeps) by the installation of security fences (Figure 5.13). In addition, deed restrictions for groundwater wells may be requested to prohibit water well installation in the area of contaminated groundwater as long as groundwater contamination poses a threat to human health or the environment. Long-term monitoring and an intrinsic remediation evaluation also is included in this alternative.

Long-term monitoring will be conducted until groundwater no longer poses a threat to human health or the environment. If intrinsic remediation is not effective and contaminant migration occurs, a contingency plan will be implemented to evaluate the associated risks and to develop strategies to address contaminant migration that poses a threat to human health or the

Horizontal barriers or other ground surface treatments may be considered to enhance surface water runoff, maximize evapotranspiration, and minimize infiltration and percolation of water through subsurface soils. Low-maintenance strategies, such as natural vegetative covers, are preferable. However, other horizontal barrier designs will be considered. Use of horizontal barriers or natural surface treatments (caps) may succeed in drying the UHSU so that VOC constituents might be treated using conventional soil vapor extraction technologies. The need and placement of horizontal barriers will be assessed using predictive models during the DAA, and will be evaluated in conjunction with capping alternatives proposed for surface and subsurface soil remediation areas.

#### 5.5.4 GRA - *In Situ* Treatment

##### Alternative 4: *In Situ* Treatment with or without Containment

Alternative 4 (Figure 5.14) consists of *in situ* treatment using air sparging/soil vapor extraction (AS/SVE), enhanced bioremediation, or passive treatment wall technologies. This alternative may include areal or local containment, if necessary, to enhance *in situ* treatment. Although numerous *in situ* treatment technologies are available, these proposed technologies were selected because of their demonstrated effectiveness and implementability.

*In situ* air sparging involves injecting air into the saturated zone to remove dissolved and residual VOCs. Air sparging is coupled with SVE so that VOCs released to the vadose zone from the saturated zone are captured, removed, and treated. Both halogenated and non-halogenated VOCs may be treated using this process. Offgas treatment may be required to meet applicable air quality standards.

*In situ* bioremediation is a process where organic contaminants are completely or partially metabolized by microorganisms present in groundwater. These organisms convert natural and xenobiotic organic compounds into water, carbon dioxide, and energy. *In situ* bioremediation of VOCs can occur under both aerobic and anaerobic environments, depending on the particular constituent. However, most chlorinated solvents are only biodegraded under anaerobic conditions through co-metabolism using secondary carbon substrates. Conditions that support co-metabolic degradation of chlorinated hydrocarbons may be locally present in OU2 groundwater. Enhanced *in situ* bioremediation fosters and optimizes natural *in situ* bioremediation and biotransformation processes that occur in groundwater by introduction of nutrients, organic substrates, and electron acceptors to the subsurface.

A passive treatment wall is a permeable reaction wall constructed of materials that will degrade VOCs or sorb, exchange, or precipitate radionuclides. Passive treatment walls are typically installed across the flowpath of a groundwater contaminant plume, so that the water passively moves through the permeable part of the wall and contaminants react with the active material in the wall. Passive treatment walls can be constructed so that the active material can be removed, disposed, and replaced when contaminant breakthrough occurs.

Figure 5.16 shows the proposed locations of *in situ* treatment components of Alternative 4. These preliminary locations were selected based on the site hydrogeology and dissolved contaminant distributions. The proposed AS/SVE unit locations shown on Figure 5.16 are designated with an "AS" prefix. AS/SVE may be implemented using either trench or well designs, depending on the saturated thickness of the UHSU. A passive treatment wall (designated with a "PTW" prefix on Figure 5.16) is proposed in the area east of the 903 Pad to remediate radionuclides present in groundwater. Proposed enhanced bioremediation locations would be similar to those selected for AS/SVE. Enhanced bioremediation would be used in lieu of AS/SVE if it is determined to be more effective during the DAA.

AS/SVE is proposed for the 903 Pad, Mound area, Trench T-2, Northeast Trenches, and at a location in the narrow part of the medial paleoscur north of the Southeast Trenches. AS/SVE will be used to remediate VOCs in both the unconsolidated geologic materials and the No. 1 Sandstone. Greater VOC concentrations typically are found in groundwater in the No. 1 Sandstone. Predictive modeling will be used to determine the appropriate spacing and location of individual AS/SVE units. If drying of the UHSU can be achieved using containment technologies, so that the unconsolidated geologic materials and No. 1 Sandstone are drained, only SVE may be required to remediate VOCs remaining in the newly created vadose zone in the UHSU.

An 800-foot-long passive treatment wall is proposed for the area east of the 903 Pad to remediate radionuclide-contaminated groundwater, but passive treatment wall technology may also be considered for remediation of groundwater VOCs. The treatment wall will be constructed so that its base is keyed into low-permeability bedrock strata. The reactive part of the treatment wall will be designed so that it can be removed, disposed, and replaced when contaminant breakthrough occurs. Containment barriers may also be used with the passive treatment wall to funnel contaminated groundwater to the wall's active treatment zone.

#### **5.5.5 GRA - *Ex Situ* Treatment**

##### **Alternative 5: Extraction with or without Containment, *Ex Situ* Treatment, and Release**

Alternative 5 (Figure 5.14) consists of groundwater extraction, *ex situ* treatment at the onsite water treatment plant, and release. Areal or local containment may be used to enhance collection and extraction of groundwater and to minimize groundwater recharge. Because of the moderately low permeabilities of the unconsolidated geologic materials and the No. 1 Sandstone, groundwater extraction generally will be accomplished using interceptor trenches, with the use of pumping where hydraulic conductivities are greater. Treatment of the contaminated groundwater for radionuclides and VOCs will be conducted at an onsite water treatment plant.

Groundwater extraction involves the use of passive or active methods to collect and remove contaminated groundwater from a site. Passive groundwater collection is accomplished by interceptor trenches or horizontal drains. Active groundwater collection is conducted via

pumping. Vertical containment may be used to locally control and route groundwater to central collection and extraction areas. Capping may be used to minimize groundwater recharge.

Figure 5.17 shows the proposed locations of extraction and containment components of Alternative 5. The preliminary locations were selected based on the site hydrogeology and dissolved contaminant distributions. About 3,500 linear feet of interceptor trenches are proposed at locations north of the 903 Pad near Seep 56, north of the Mound area near Seep 59, downgradient of Trench T-2, near Seep 64, downgradient of the Northeast Trenches, and across the narrow part of the medial paleoscut north of the Southeast Trenches. These trenches are designated with an "IT" prefix on Figure 5.17. Three pumping wells (designated W-1, W-2, and W-3 on Figure 5.17) are proposed beneath and adjacent to the 903 Pad. These wells are proposed to locally extract more highly contaminated groundwater in these areas.

A 1,200-foot-long vertical barrier (designated VB-1 on Figure 5.17) is proposed upgradient (west) of the 903 Pad to minimize groundwater inflow to OU2. A natural soil/vegetative cover may be installed over the areas encompassed by the 903 Pad, Mound, Trench T-2, and Northeast Trenches to maximize surface water runoff and evapotranspiration, so that groundwater recharge is minimized. Limiting groundwater recharge will result in lowering the groundwater table, reducing the saturated thickness, increasing the thickness of the vadose zone, and minimizing the quantity of groundwater collected and treated. Determination of the effectiveness of groundwater extraction and treatment will be assessed during the DAA. Specific interceptor trench or pumping well configurations and locations and the need for containment or capping will be determined using predictive model simulations.

## 6.0 LOCATION- AND ACTION-SPECIFIC APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

The DOE is responsible for identifying those promulgated standards, requirements, criteria, or limitations to be met during implementation of the selected remedy. *Applicable* requirements are those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental, or state environmental or facility citing laws that specifically address a hazardous substance, pollutant, contaminant remedial action, location, or other circumstance at a CERCLA site. *Relevant and appropriate* requirements are those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental, or state environmental or facility citing laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site. Only state standards that are promulgated and identified in a timely manner by the state, and are more stringent than federal requirements, qualify as ARARs. For purposes of identification and notification of state standards, the term "promulgated" means that the standards are of general applicability and are legally binding.

In addition to ARARs, other non-promulgated advisories, criteria, or guidance documents that are to-be-considered (TBCs) to supplement an ARAR provision for a particular release may be identified. The TBCs are not legally binding. However, the TBCs can be used, when suitable, to determine the level of cleanup required to protect human health and the environment.

The EPA has established the three ARAR categories. The categories are used as guidance since some ARARs do not necessarily fall into this classification system. They include the following.

- Chemical-specific requirements are usually health- or risk-based numerical values or methodologies which, when applied to site-specific conditions, result in the establishment of numerical values. These values establish the acceptable amount or concentration of chemical that may be found in or discharged to the ambient environment via air emissions, wastewater discharges, or other routes.
- Location-specific requirements are restrictions placed on the concentration of hazardous substances solely because they occur in special locations. Typical location restrictions include areas with sensitive or unique characteristics such as wetlands, areas of historical significance, or areas situated in locations requiring special precautions because of seismic activity or flood plains.
- Action-specific requirements are usually technology- or activity-based requirements or limitations on actions taken with respect to management of the remediation waste or closure of the facility. These requirements are triggered by the particular remedial activities that are selected to accomplish a remedy.

55

Chemical-specific ARARs/TBCs that were previously identified for OU2 are presented in Tables 2.2, 2.3, and 2.4 for surface soils, subsurface soils, and groundwater, respectively. Potential location- and action-specific ARARs/TBCs have been identified for each remedial alternative presented in Section 5.0 and are summarized in Tables 6.1 through 6.5. Location- and action-specific ARARs/TBCs will be further evaluated and refined, and each alternative will be evaluated with respect to compliance with the ARARs/TBCs during the DAA.

As discussed in Section 2.1, IHSSs that are associated with source areas for surface and subsurface soil contamination have been identified as likely candidates for non-time-critical removal actions. The National Contingency Plan (NCP) states that removal actions under CERCLA Section 104 and removal actions pursuant to CERCLA Section 106 shall, to the extent practicable considering the exigencies of the situation, attain ARARs under federal environmental or state environmental or facility citing laws. [40 CFR 300.415(i)]. As such, the ARARs/TBCs identified in Tables 6.1 and 6.2 should be considered in the design and implementation of source removal actions for surface and subsurface soil.

56

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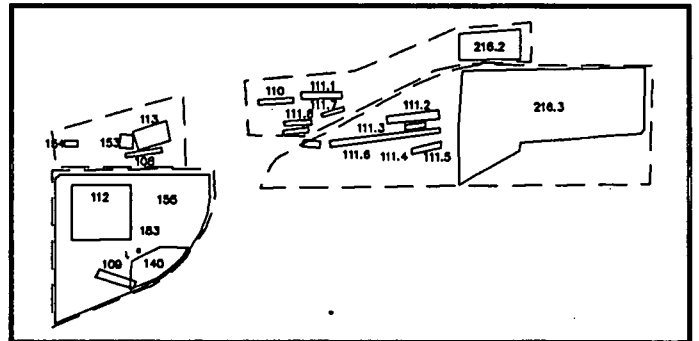
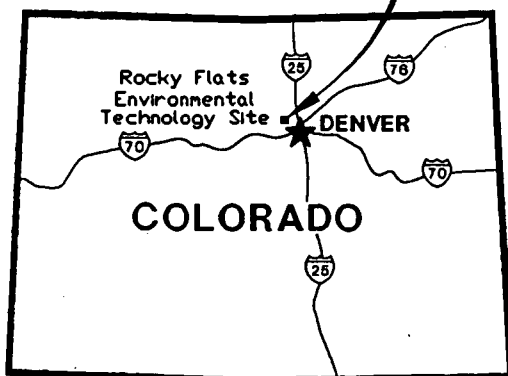
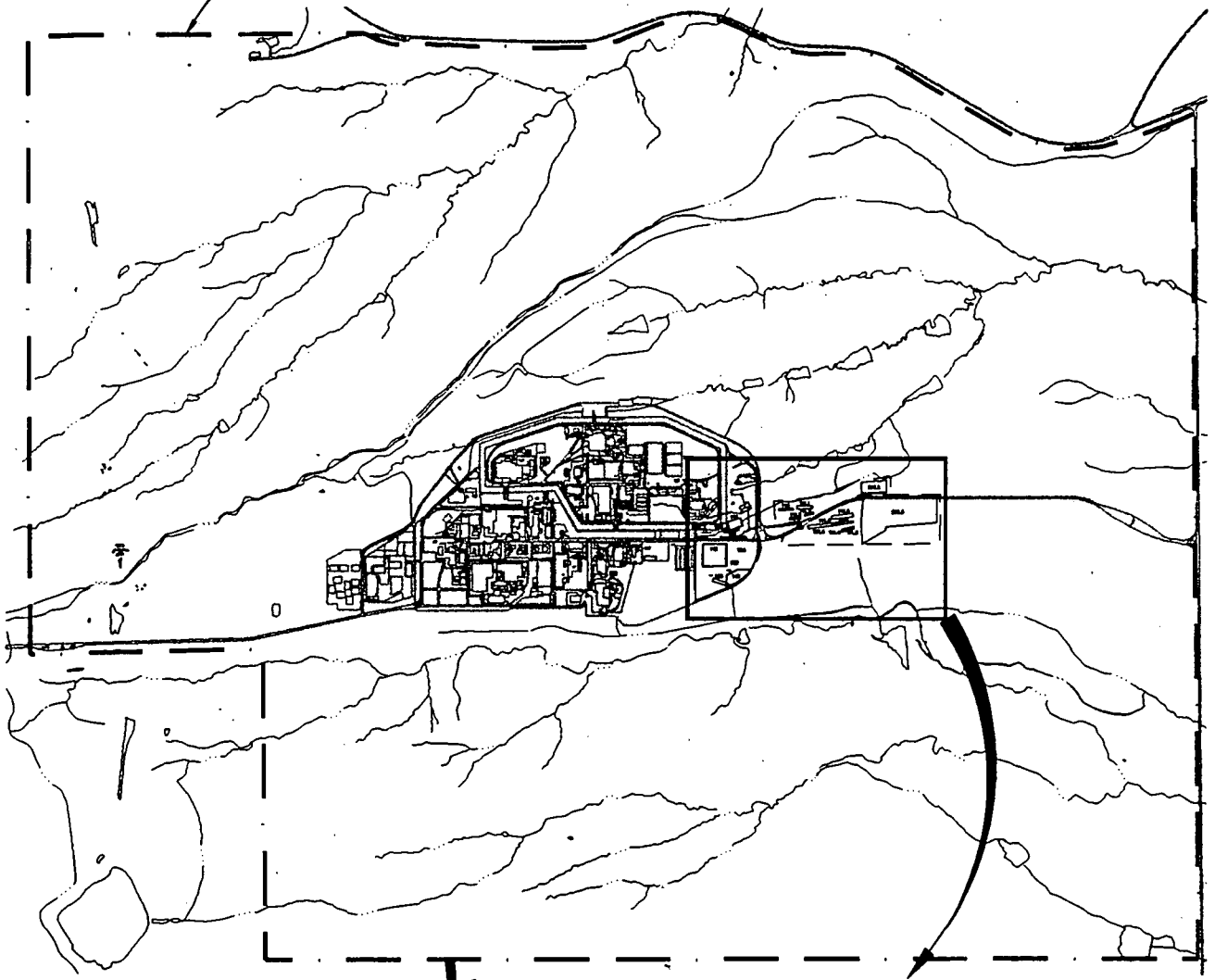
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## FIGURES

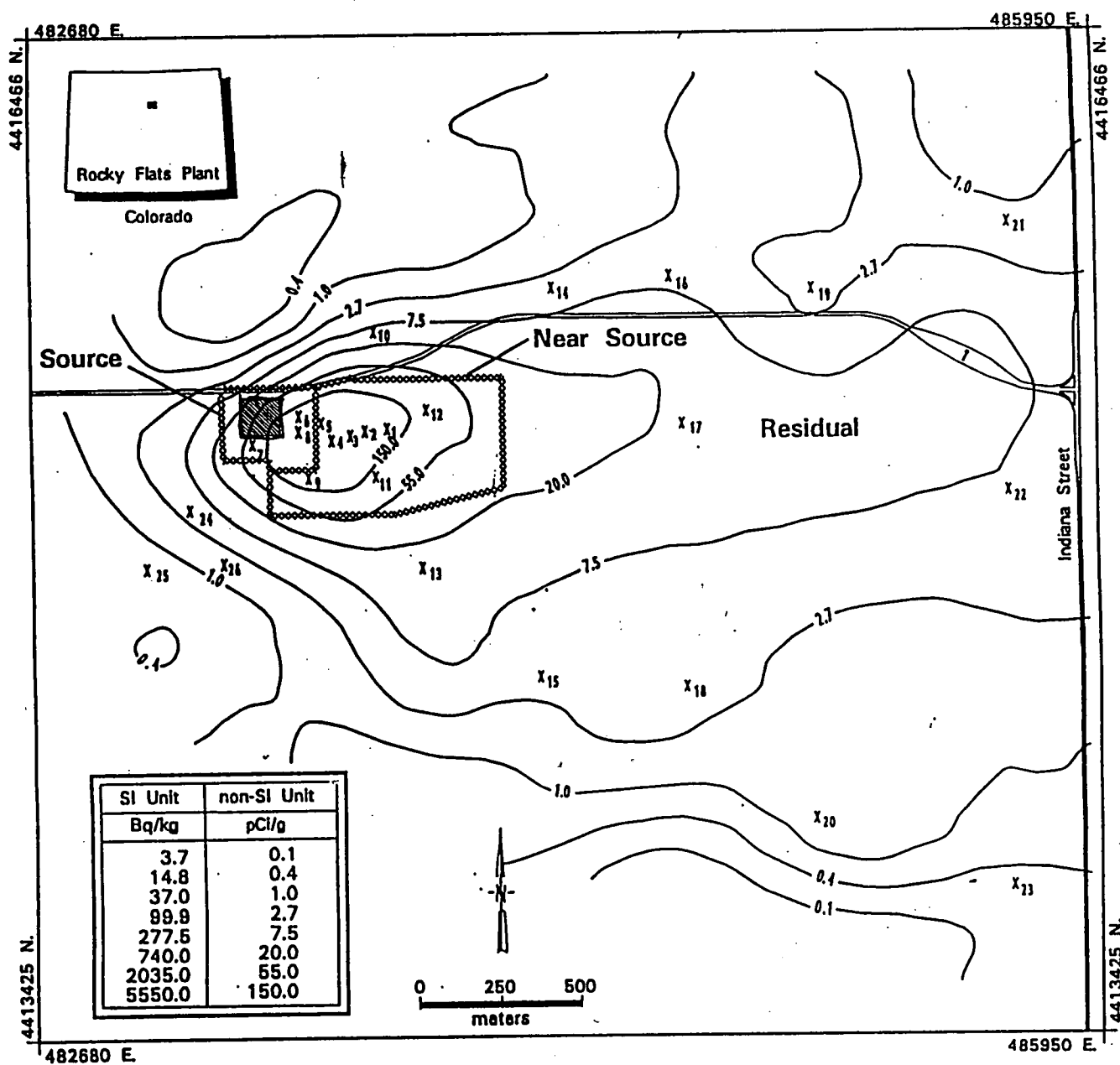
**ROCKY FLATS ENVIRONMENTAL  
TECHNOLOGY SITE BOUNDARY**



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**Figure 2.1**

**Operable Unit No. 2  
Technical Memorandum No. 2  
Location Map**



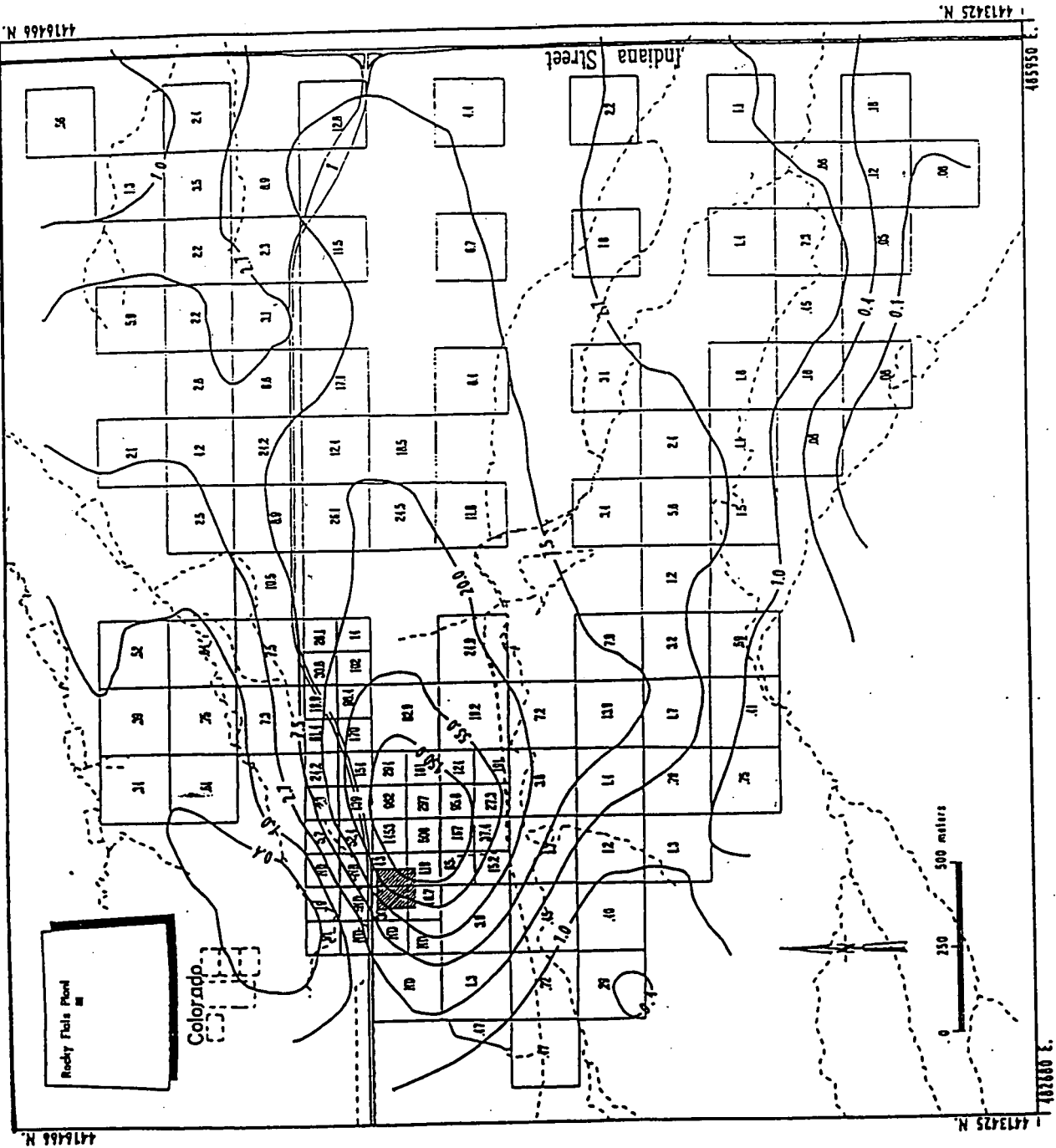
SI Unit	non-SI Unit
Bq/kg	pCi/g
3.7	0.1
14.8	0.4
37.0	1.0
99.9	2.7
277.5	7.5
740.0	20.0
2035.0	55.0
5550.0	150.0

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Figure 2.3

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 Technical Memorandum No. 2

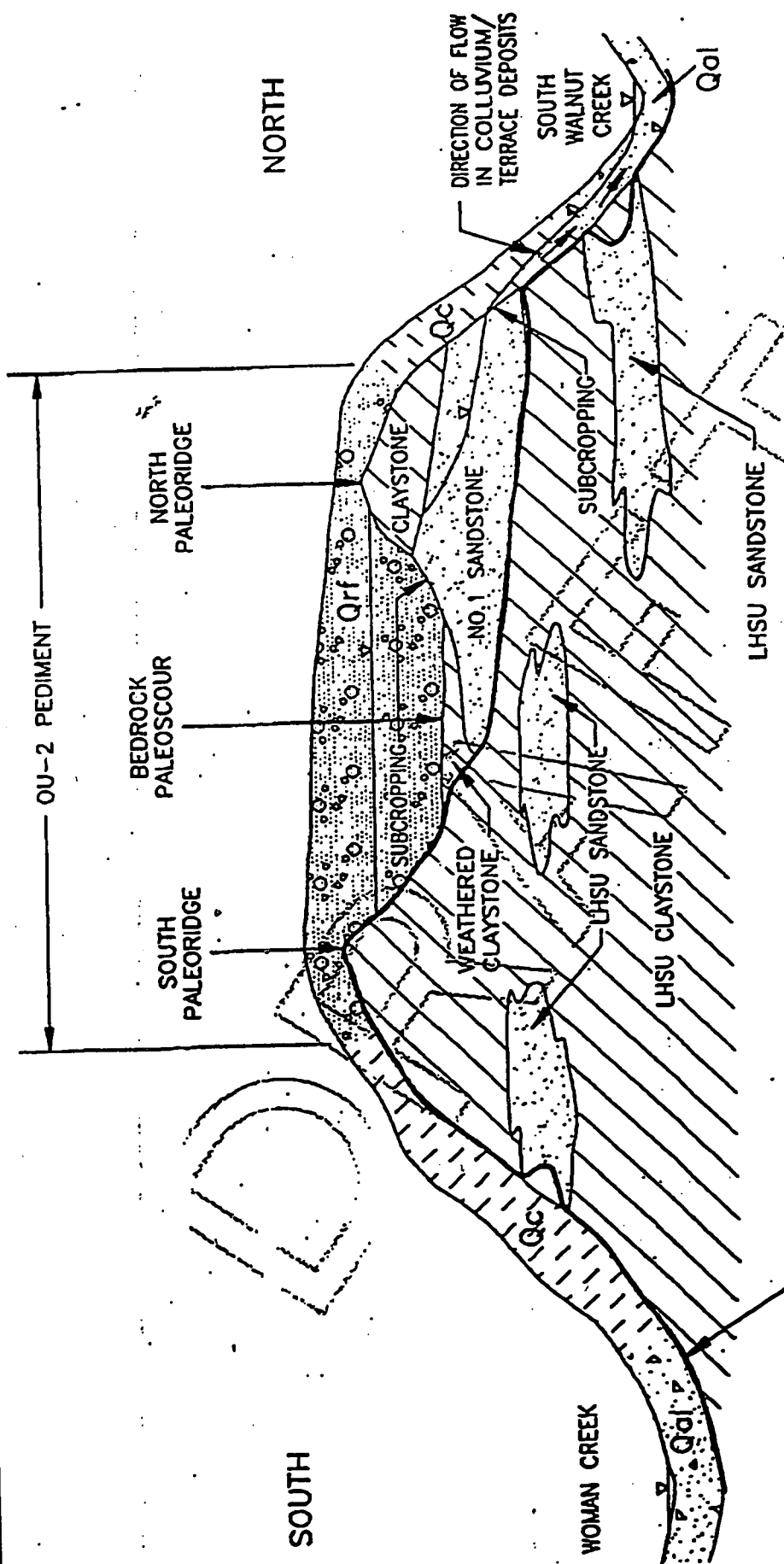
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Figure 2.4

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EXPLANATION

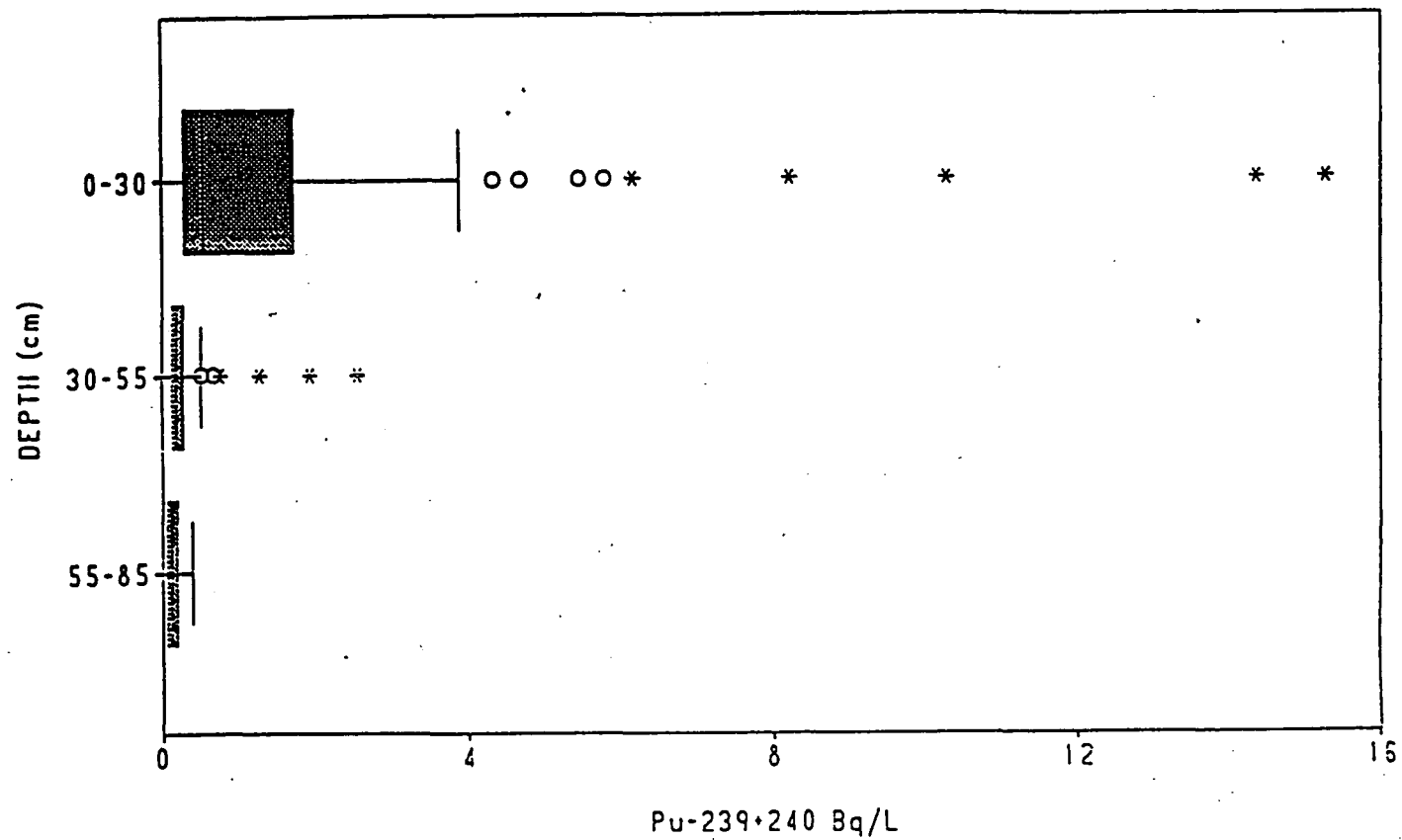
- Qrf ROCKY FLATS ALLUVIUM
- QC COLLUVIUM/TERRACE DEPOSITS
- Qol VALLEY FILL ALLUVIUM
- UHSU UPPER HYDROSTRATIGRAPHIC UNIT
- LHSU LOWER HYDROSTRATIGRAPHIC UNIT
- CONCEPTUAL UHSU/LHSU BOUNDARY

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Figure 2.6

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Schematic Cross-Section  
of Hydrostratigraphy at OU-2

69

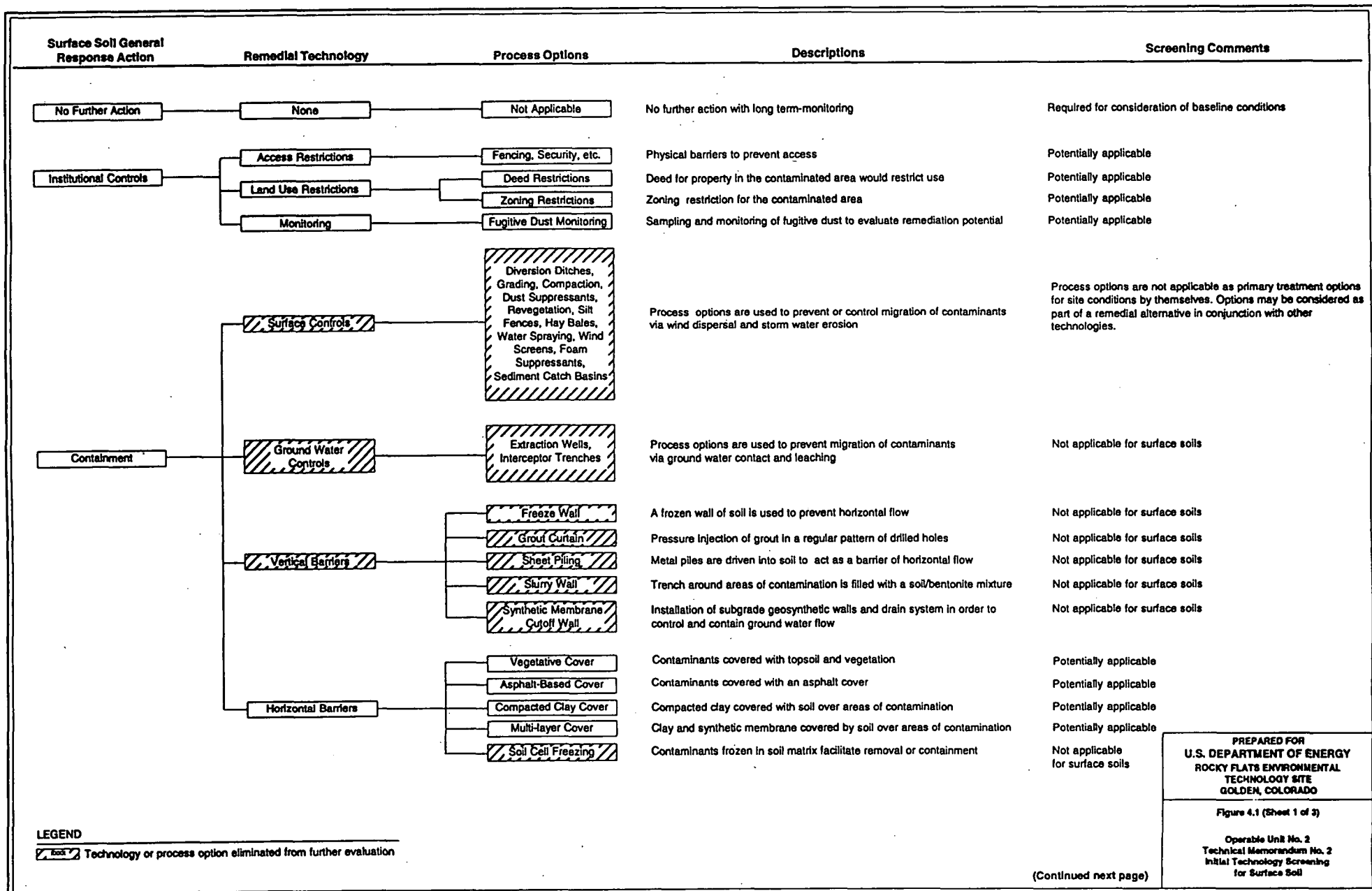


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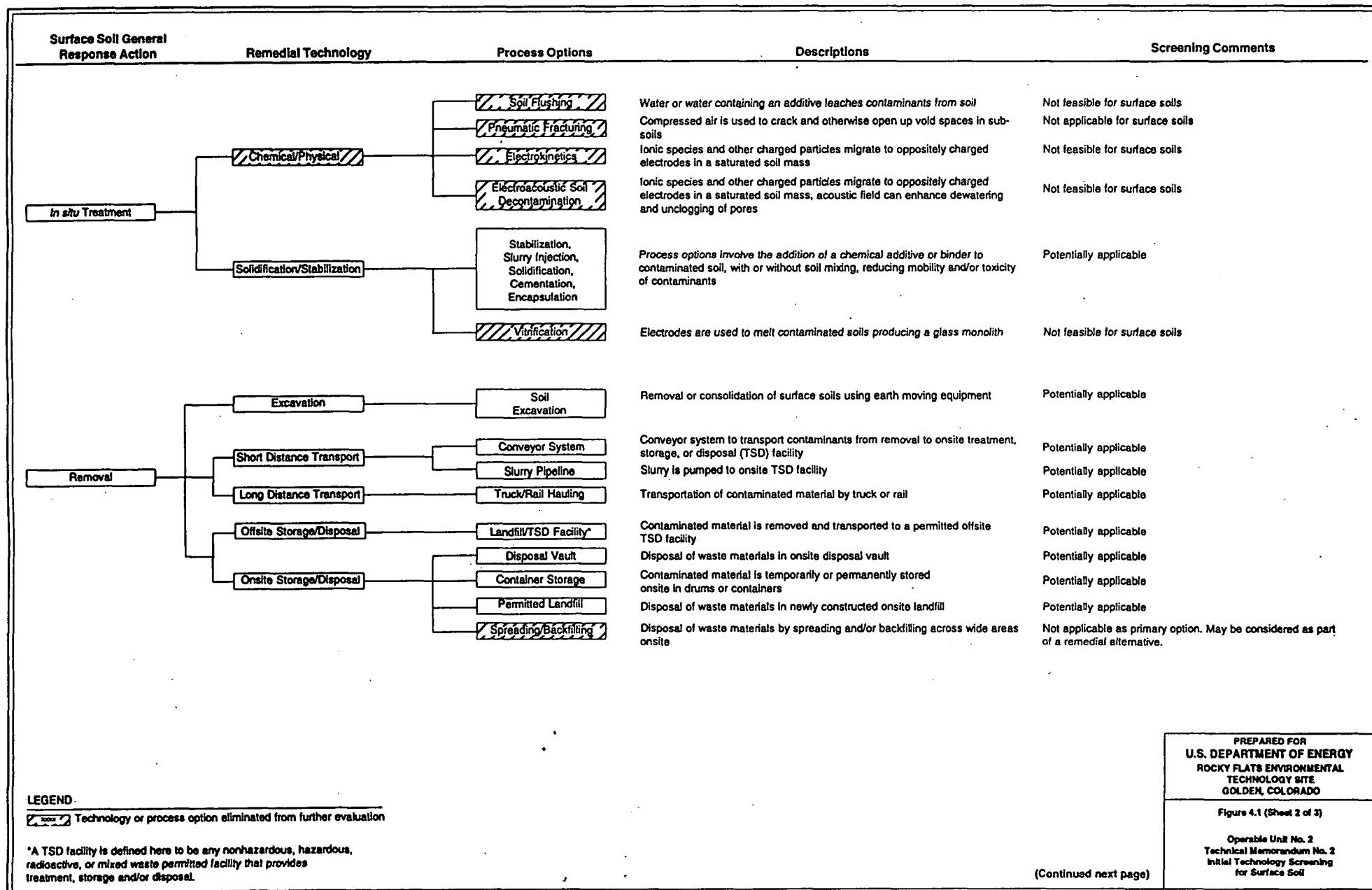
Figure 2.8

Operable Unit No. 2  
Technical Memorandum No. 2

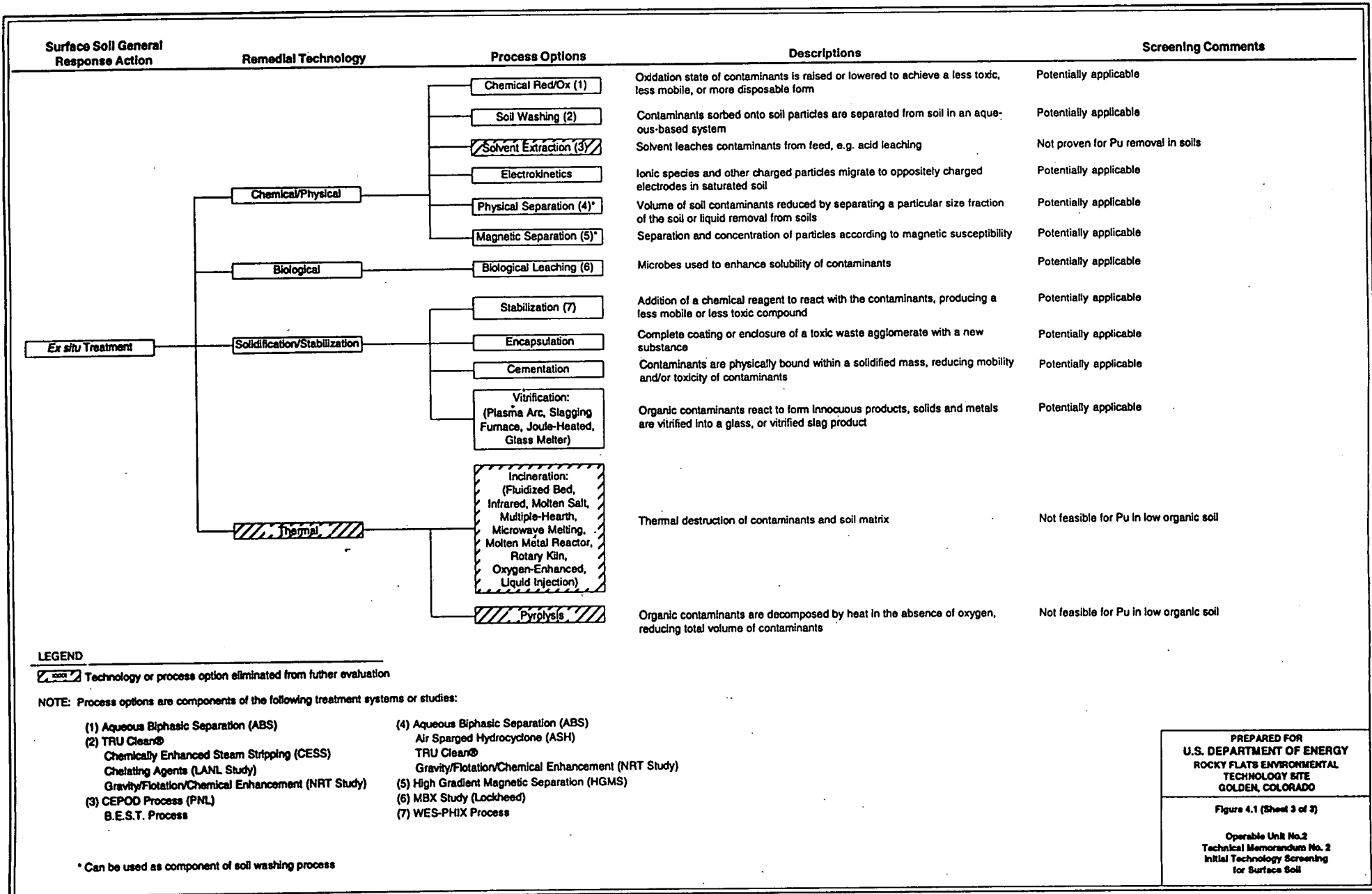
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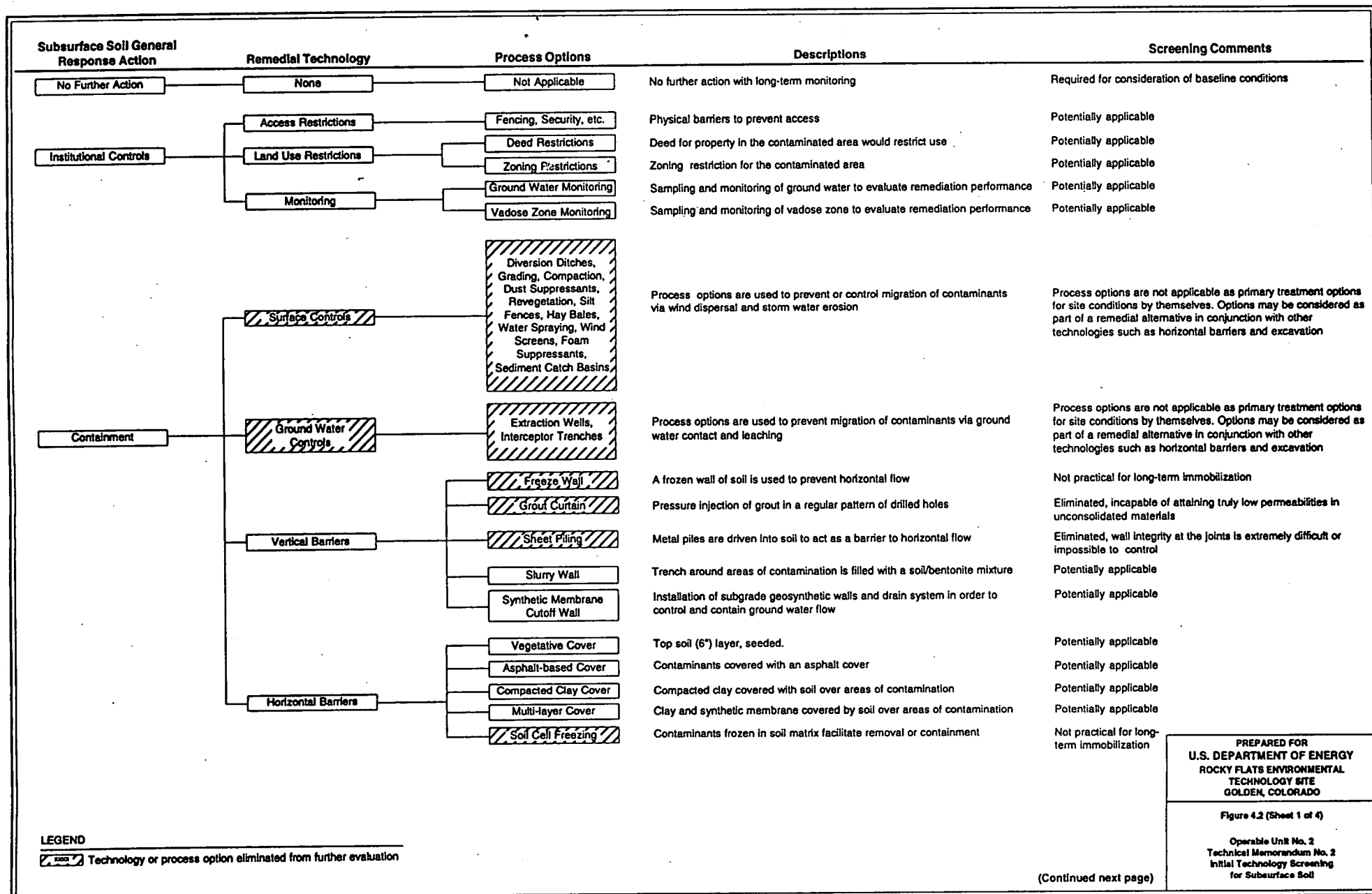


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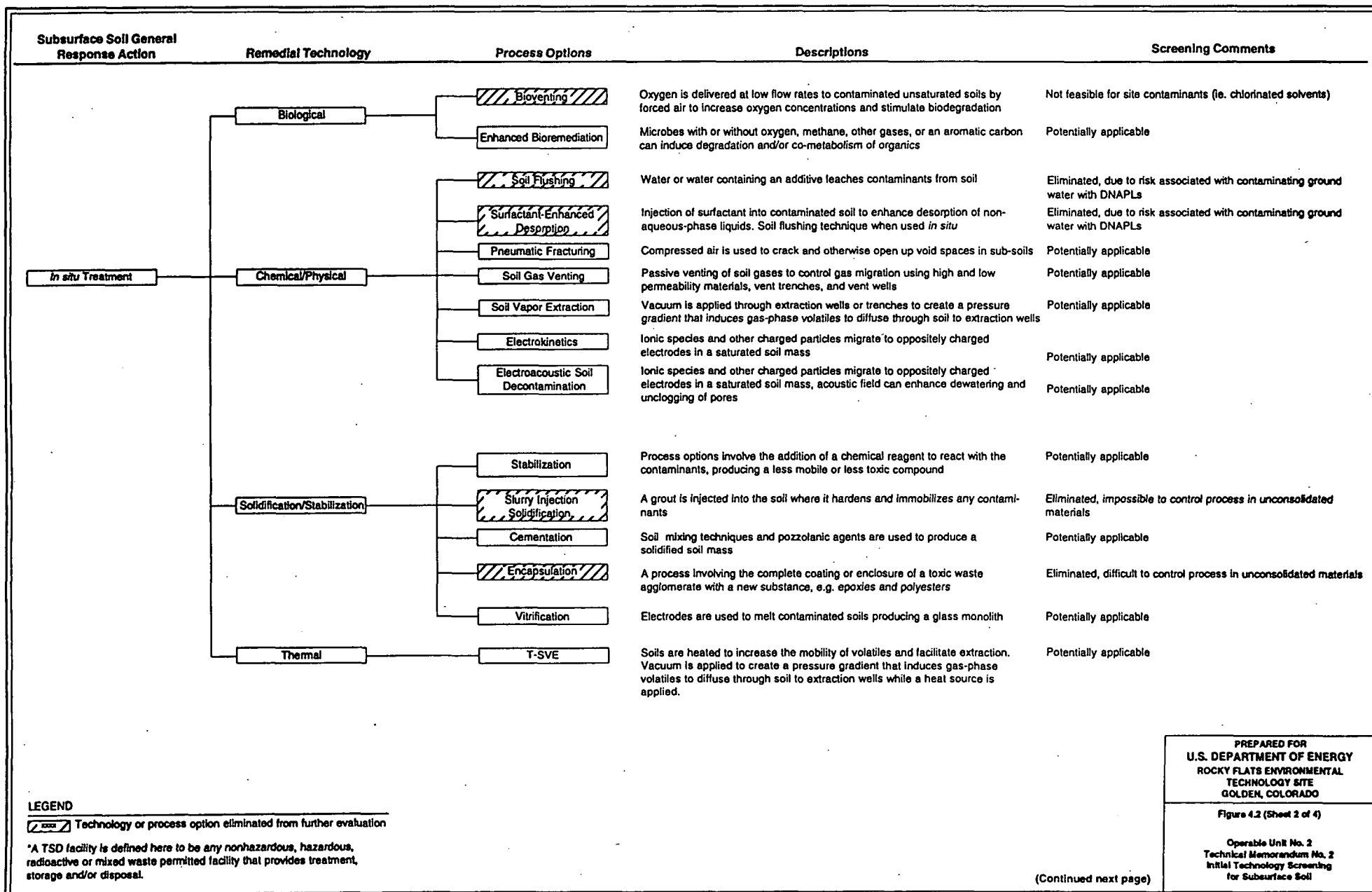


26





64



LEGEND

 Technology or process option eliminated from further evaluation

\*A TSD facility is defined here to be any nonhazardous, hazardous, radioactive or mixed waste permitted facility that provides treatment, storage and/or disposal.

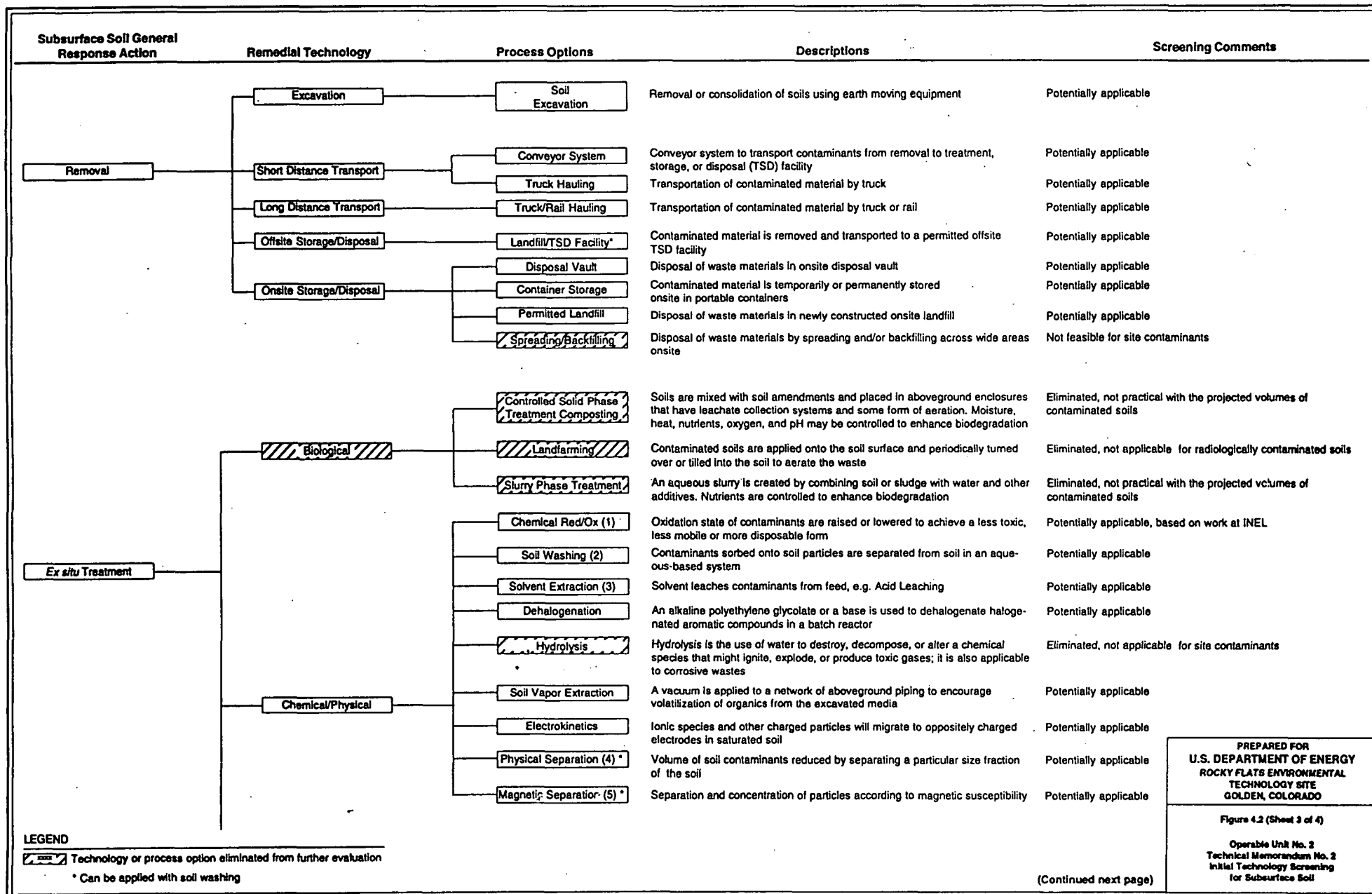
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Figure 4.2 (Sheet 2 of 4)

Operable Unit No. 2  
Technical Memorandum No. 2  
Initial Technology Screening  
for Subsurface Soil

(Continued next page)


75



96

Subsurface Soil General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
Ex situ Treatment	Solidification/Stabilization	Stabilization (6)	Process that involves the addition of a chemical reagent to react with the contaminants, producing a less mobile or less toxic compound	Potentially applicable
		Encapsulation	A process involving the complete coating or enclosure of a toxic waste agglomerate with a new substance, e.g. epoxies and polyesters	Potentially applicable
		Cementation	Contaminants are physically bound within a solidified mass	Potentially applicable
		Vitrification: (Plasma Arc, Slagging Furnace, Joule-Heated, Glass Melter)	Organic contaminants react to form innocuous products, solids and metals are vitrified into a glass, or vitrified slag product	Potentially applicable
	Thermal	Incineration: (Fluidized Bed, Infrared, Molten Salt, Solar Multiple-Hearth, Microwave Melting, Molten metal reactor, Rotary Kiln, Oxygen-Enhanced, Liquid Injection, High Temperature Fluid Wall)	Thermal destruction of organic contaminants in soils, reducing total volume of contaminants	Potentially applicable
		High-Temperature Thermal Desorption	Wastes are heated to 600-1000°F to volatilize water and organic contaminants	Eliminated, low-temperature thermal desorption is preferred process for VOCs
		Low-Temperature Thermal Desorption	Wastes are heated to 200-600°F to volatilize water and organic contaminants	Potentially applicable
		HTS Thermal Distillation Process	Soils are heated in a nitrogen atmosphere to volatilize VOCs and SVOCs	Potentially applicable
		Supercritical Water Oxidation, Wet Air Oxidation	Organics are oxidized in water mixture	Not directly applicable for unsaturated soils. Options may be considered as part of remedial alternatives in which soils are treated as part of an aqueous process.
		Pyrolysis	Organics decomposed by heat in the absence of oxygen	Potentially applicable

LEGEND

 Technology or process option eliminated from further evaluation

NOTE: Process options are components of the following treatment systems or studies:

(1) Aqueous Biphasic Separation (ABS)

(2) TRU Clean®

Surfactant Enhanced Remediation

Aqueous Biphasic Separation

Chemically Enhanced Steam Stripping (CESS)

Chelating Agents (LANL Study)

Gravity/Floation/Chemical Enhancement (NRT Study)

(3) CEPOD Process (PNL)

B.E.S.T. Process

(4) Aqueous Biphasic Separation (ABS)

Surfactant Enhanced Remediation

Air Sparged Hydrocyclone (ASH)

TRU Clean®

Gravity/Floation/Chemical Enhancement (NRT Study)

(5) High Gradient Magnetic Separation (HGMS)

(6) WES-PHIX Process

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Figure 4.2 (Sheet 4 of 4)

Operable Unit No. 2

Technical Memorandum No. 2

Initial Technology Screening

for Subsurface Soil

Groundwater General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
No Further Action	Intrinsic Remediation	Groundwater Monitoring	No further action with long-term sampling, analysis, and monitoring to evaluate intrinsic remediation	Required for consideration of baseline conditions
Institutional Controls	Access Restrictions	Fencing, Security	Physical barriers to prevent access	Potentially applicable
		Lock Out/Tag Out Wells	Physical barriers to prevent access	Potentially applicable
	Land Use Restrictions	Deed Restrictions	Deed modifications on property in the contaminated area would restrict use	Potentially applicable
		Zoning Restrictions	Zoning restriction for the contaminated area	Potentially applicable
	Intrinsic Remediation	Regulatory Restrictions	Local regulation prohibiting installation of water well in contaminated area	Potentially applicable
Containment	Surface Water Controls	Groundwater Monitoring	Long-term sampling, analysis and monitoring of groundwater to evaluate intrinsic remediation	Potentially applicable
		Enhanced Soil Treatment, Revegetation, Grading, and Compaction	Process options used to enhance surface water runoff and maximize evapotranspiration and to minimize infiltration and percolation of water and contaminant leaching to groundwater	Potentially applicable
	Groundwater Controls	Interceptor Trenches and Local Extraction Wells	Processes that intercept and extract contaminated groundwater	Potentially applicable
		Freeze Wall	A frozen wall of soil is used to prevent horizontal flow	Eliminated; not long-term solution
	Vertical Barriers	Grout Curtain	Subsurface barrier created by high pressure injection of grout into unconsolidated material or bedrock fractures	Eliminated; incapable of attaining low permeabilities in unconsolidated materials
		Sheet Piling	Installation of subgrade sheet pile wall as a groundwater barrier	Potentially applicable
		Slurry Wall	Installation of low-permeability, subgrade slurry wall for groundwater control	Potentially applicable
		Synthetic Membrane Cutoff Wall	Installation of subgrade HDPE walls and drain system to contain groundwater	Potentially applicable
		Asphalt-Type Cover	An asphalt-type cover over contaminated areas to enhance surface water runoff and reduce water percolation and leaching of contaminants to groundwater	Potentially applicable
	Horizontal Barriers	Compacted Clay Cover	A compacted clay cover over contaminated areas to enhance surface water runoff and reduce water percolation and leaching of contaminants to groundwater	Potentially applicable
		Multi-Layer Cover	Compacted clay and/or geosynthetics cover over contaminated areas to enhance surface water runoff and reduce water percolation and leaching of contaminants to groundwater	Potentially applicable
		Soil Cell Freezing	Contaminants frozen in soil matrix prevent percolation and leaching of contaminants to groundwater	Eliminated; not long-term solution
Removal	Groundwater Extraction	Interceptor Trenches and Local Extraction Wells	Processes that intercept and extract contaminated groundwater	Potentially applicable
		Truck/Rail Hauling Pipeline	Process options that are used to transport contaminated groundwater	Potentially applicable
	Disposal	Discharge to POTW	Process options that are used to dispose contaminated groundwater	Eliminated; off-site facilities can not treat radionuclides
		RFETS STP	Transport to RFETS sewage treatment plant for disposal	Potentially applicable
	Storage	Storage Tanks, Drum Storage	Process options for the permanent or temporary storage of untreated groundwater	Eliminated; not long-term solution

LEGEND

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Figure 4.3 (Sheet 1 of 4)

Operable Unit No. 2  
Technical Memorandum No. 2  
Initial Technology Screening  
for Groundwater

(Continued next page)

86

Groundwater General Response Action	Remedial Technology	Process Options	Descriptions	Screening Comments
In Situ Treatment	Enhanced Bioremediation	Enhancement of aerobic or anaerobic conditions, cometabolic substrates	Injection of oxygen, nutrients, electron acceptors into groundwater to enhance the degradation and/or cometabolism of organics	Potentially applicable
		Hydrofracturing	Water and/or slurred sand is forced at high pressure into contaminated zone, creating pathways and fractures to enhance groundwater flow in the subsurface	Eliminated; presence of DNAPLs at site requires detailed understanding and control of fracture/pathway orientation
		Precipitation, Red/Ox	Injection of chemical into contaminated groundwater to reduce and precipitate radionuclides	Eliminated; not long-term solution
		Surfactant-Enhanced Desorption (1)	Injection of surfactant into contaminated groundwater to enhance desorption of nonaqueous-phase liquids (NAPLs)	Eliminated; difficult to control desorbed DNAPL movement
		Air Sparging	Injection of air into groundwater to remove volatile organic compounds	Potentially applicable
	Chemical/Physical	Free Product Recovery	Undissolved NAPLs are extracted from subsurface	Eliminated; part of source removal under EE/CA
		Adsorption, Absorption	See Passive Treatment Wall	Eliminated; component of passive treatment wall
		Passive Treatment Wall	Construction of <i>in situ</i> treatment wall to degrade, sorb, exchange, or precipitate volatile organic compounds and radionuclides in contaminated groundwater	Potentially applicable
		Electrokinetics	Groundwater flow toward extraction well is accelerated with the use of direct current applied to electrodes placed in the contamination plume	Eliminated; difficult to implement
		Ion-Exchange	See Passive Treatment Wall	Eliminated; component of passive treatment wall
	Solidification/Stabilization	Cementation, Soil Mix Wall, Soil Mixing	Aquifer materials are mixed with cementitious materials to form a solidified matrix	Eliminated; maybe potentially applicable as a vertical barrier but not as sitewide groundwater treatment
		Thermal		
	Thermal	Steam Stripping	Steam is forced into an aquifer through injection wells to vaporize VOC and SVOC contaminants.	Eliminated; difficult to hydraulically control process
		T-SVE	Saturated zone is heated to increase the mobility of volatiles. Vacuum applied to create a pressure gradient that induces gas-phase volatiles to diffuse through soil to extraction wells.	Potentially applicable for organics

LEGEND

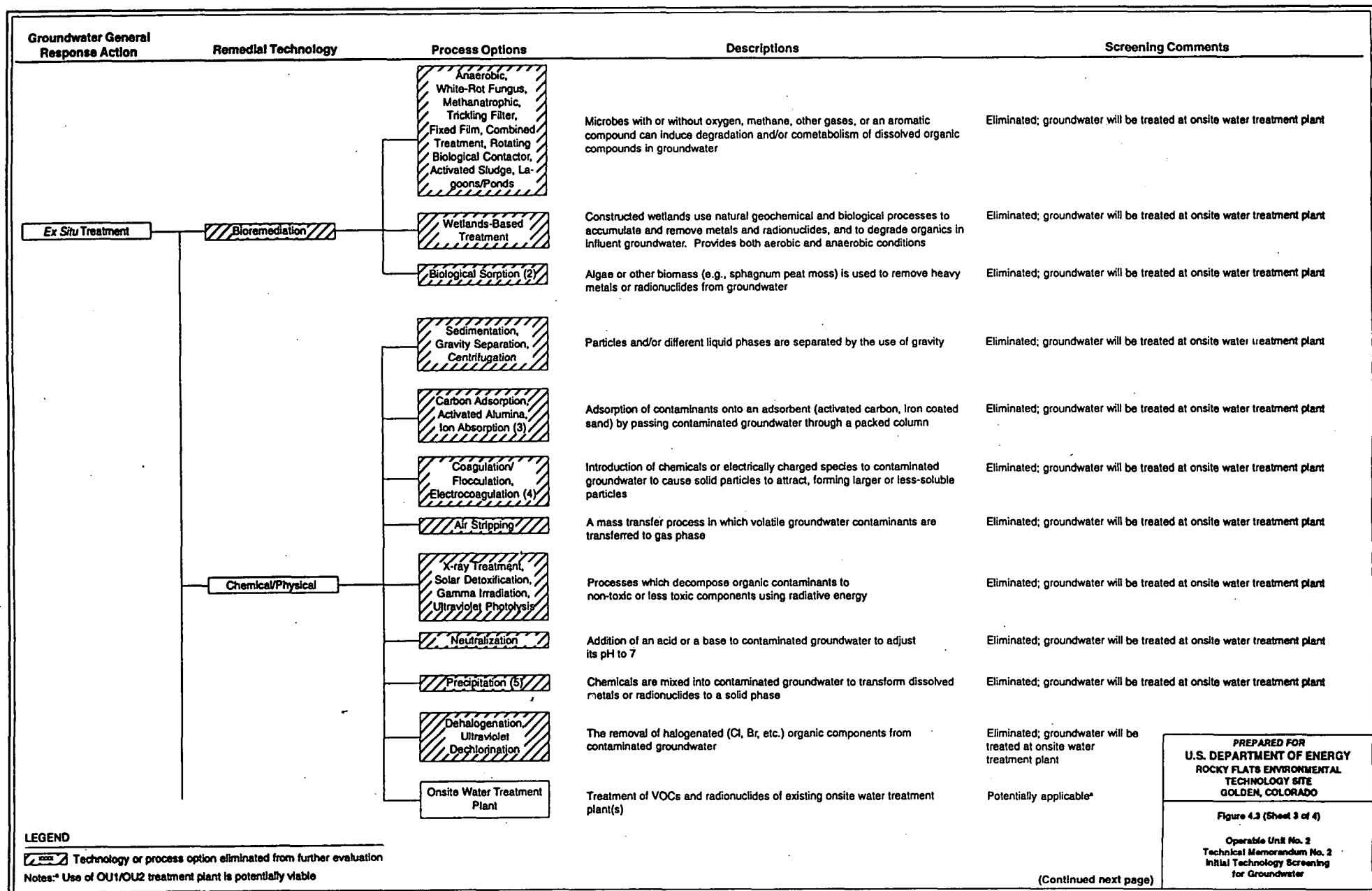
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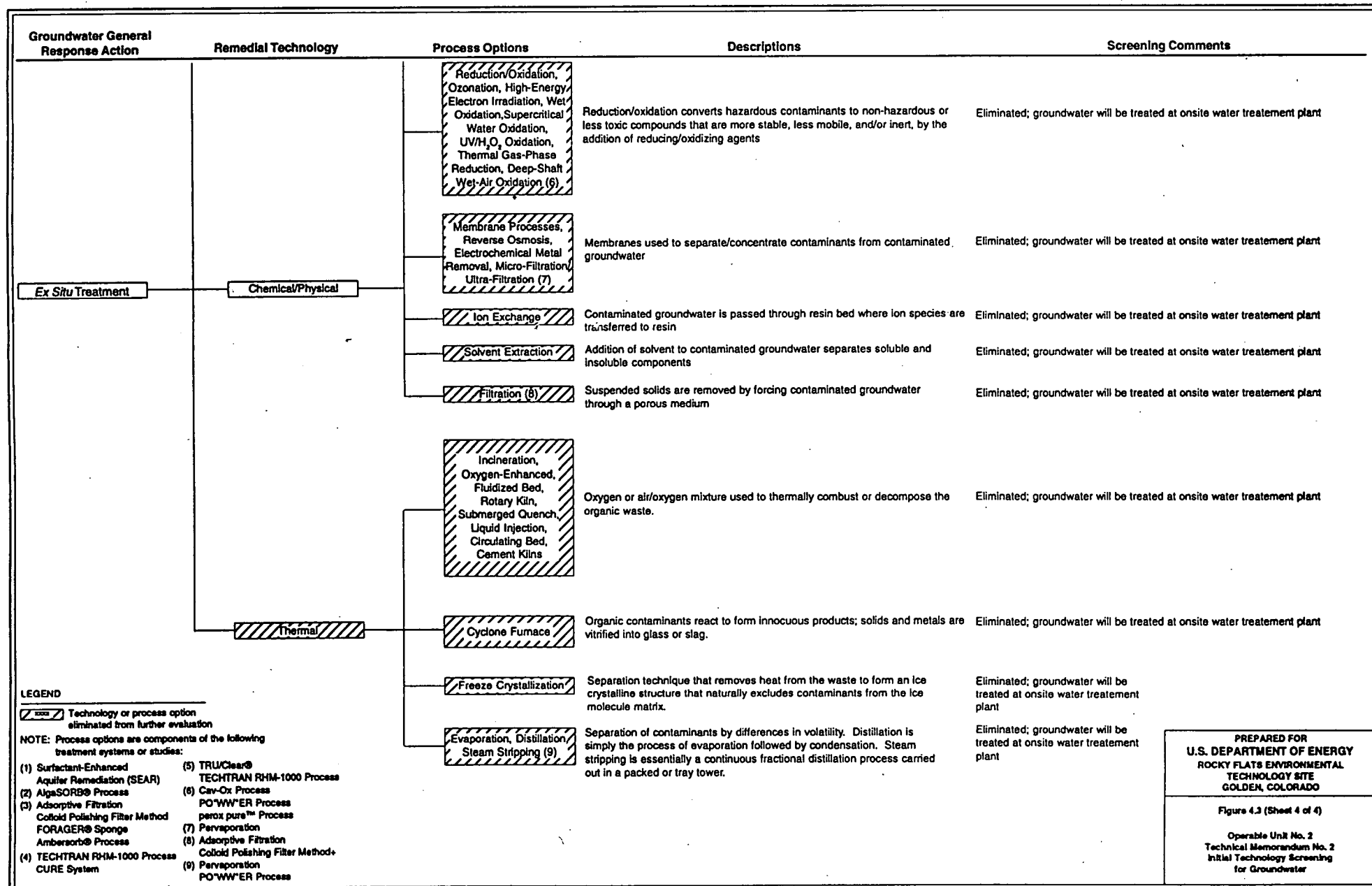
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Figure 4.3 (Sheet 2 of 4)

Operable Unit No. 2  
Technical Memorandum No. 2  
Initial Technology Screening  
for Groundwater





Surface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost <sup>a</sup>
No Further Action	None	Not Applicable	Does not achieve C/RAOs	Difficult regulatory/community acceptance	None
Institutional Controls	Access Restrictions	Fencing, Security, etc.	May achieve C/RAOs. Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, low O&M
		Deed Restrictions	May achieve C/RAOs. Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, low O&M
		Zoning Restriction	May achieve C/RAOs. Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, low O&M
		Fugitive Dust Monitoring	Effective monitoring method	Easily implemented	Low capital, low O&M
Containment	Horizontal Barriers	Vegetative Cover	May achieve C/RAOs with restrictions on future land use	Easily implemented.	Low capital, low O&M
		Asphalt-Based Cover	May achieve C/RAOs with restrictions on future land use	Easily implemented.	Low capital, low O&M
		Compacted-Clay Cover	May achieve C/RAOs with restrictions on future land use	Easily implemented.	Med capital, low O&M
		Multi-Layer Cover	May achieve C/RAOs with restrictions on future land use	Easily implemented.	High capital, med O&M
In situ Treatment	Solidification/Stabilization	Stabilization, Slurry Injection, Solidification, Cementation, Encapsulation	Effectiveness and reliability evaluations require treatability study. Long-term effectiveness suspect.	Average implementability	Insufficient data

**LEGEND**

Technology or process option eliminated from further evaluation  
 Notes: <sup>a</sup> Cost evaluation is relative only within remedial technology groupings.

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Figure 4.4 (Sheet 1 of 3)

Operable Unit No. 2  
 Technical Memorandum No. 2  
 Technology Evaluation for  
 Surface Soils

(Continued next page)

28

Surface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Removal	Excavation	Soil Excavation	Appears to meet C/RAOs. Would require controls to prevent mobilization of contaminants	Easily implemented	Low capital, low O&M
	Short Distance Transport	Conveyor System	Effective, contaminants are removed. Would require controls to prevent mobilization of contaminants	Easily implemented	High capital, med O&M
		Slurry Pipeline	Effective, contaminants are removed. Would require controls to prevent mobilization of contaminants	Easily implemented	High capital, high O&M
	Long Distance Transport	Truck/Rail Hauling	Effective, contaminants are removed. Would require controls to prevent mobilization of contaminants	Easily implemented, DOT permits may be required	High capital, low O&M
	Offsite Storage/Disposal	Landfill/TSD Facility	Effective, reduces mobility of contaminants. Would require controls to prevent mobilization of contaminants	Easily implemented	High capital, low O&M
	Onsite Storage/Disposal	Disposal Vault	Effective, reduces mobility of contaminants. Would require controls to prevent mobilization of contaminants	Difficult implementation, would require permits, and construction of onsite TSD facility	High capital, low O&M
		Container Storage	Effective, reduces mobility of contaminants. Would require controls to prevent mobilization of contaminants	Difficult implementation, RFETS has permitted storage areas; however, capacity may be limited. Long-term storage may not be acceptable	Low capital, med O&M
		Permitted Landfill	Effective, reduces mobility of contaminants. Would require controls to prevent mobilization of contaminants	Difficult implementation, would require permits and construction of onsite TSD facility	High capital, med O&M

LEGEND

 Technology or process option eliminated from further evaluation

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Figure 4.4 (Sheet 2 of 3)

Operable Unit No. 2  
Technical Memorandum No. 2  
Technology Evaluation for  
Surface Soils

(Continued next page)

Surface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Ex situ Treatment	Chemical/Physical	Chemical Red/Ox (1)	Effectiveness and reliability evaluations require treatability study. Current work at INEL on U looks promising	Insufficient data available to rate this process option	Insufficient data
		Soil Washing (2)	Effectiveness and reliability evaluations require treatability study. Current treatability work looks promising.	Average implementability	Med capital, med O&M
		Electrokinetics	Effectiveness and reliability evaluations require treatability study. Current work on Cr, Hg, and U looks promising	Difficult implementation, innovative technology	High capital, med O&M
		Physical Separation (4)	Effectiveness and reliability evaluations require treatability study. Current work on Ra, and U looks promising	Easily implemented	Low capital, low O&M
		Magnetic Separation (5)	Effectiveness and reliability evaluations require treatability study. Current work at RFETS and INEL looks promising.	Difficult implementation, innovative technology	Insufficient data
	Biological	Biological Leaching (6)	Effectiveness and reliability evaluations require treatability study. Work at RFETS in early stages.	Insufficient data available to rate this process option.	Insufficient data
	Solidification/Stabilization	Stabilization (7)	Effectiveness and reliability evaluations require treatability study. Effectiveness for heavy metals is established.	Average implementability, TSD services for heavy metals may be applicable	Insufficient data
		Encapsulation	Effective, appears to meet C/RAOs. Would require controls to prevent mobilization of contaminants	Average implementability	Medium capital, med O&M
		Cementation	Average effectiveness, appears to meet C/RAOs. Would require controls to prevent mobilization of contaminants	Easily Implemented	Low capital, med O&M
		Vitrification: (Plasma Arc, Slagging Furnace, Joule-Heated, Glass Melter)	Effective, appears to meet C/RAOs. Would require controls to prevent mobilization of contaminants	Average implementability	Medium-high capital, med-high O&M

NOTE: Process options are components of the following treatment systems or studies:



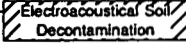
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|--|--|
| (1) Aqueous Biphasic Separation (ABS)              | (4) Aqueous Biphasic Separation (ABS)              |
| (2) TRU Clean®                                     | Air Sparged Hydrocyclone (ASH)                     |
| Gravity/Flotation/Chemical Enhancement (NRT Study) | TRU Clean®   |
| Chemically Enhanced Steam Stripping (CESS)         | Gravity/Flotation/Chemical Enhancement (NRT Study) |
| Chelating Aquants (LANL Study)                     | (5) High Gradient Magnetic Separation (HGMS)       |
| (3) CEPOD Process (PNL)                            | (6) MBX Study (Lockheed)                           |
| B.E.S.T. Process                                   | (7) WES-PHIX Process                               |

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Figure 4.4 (Sheet 3 of 3)


Operable Unit No. 2  
Technical Memorandum No. 2  
Technology Evaluation for  
Surface Soils

84

Subsurface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
No Further Action	None	Not Applicable	Does not achieve C/RAOs in source areas	Difficult regulatory/community acceptance	None
Institutional Controls	Access Restrictions	Fencing, Security, etc.	Does not achieve C/RAOs in source areas	Difficult regulatory/community acceptance	Med capital, low O&M
	Land Use Restrictions	Deed Restrictions	Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, no O&M
		Zoning Restriction	Effectiveness depends on continued future implementation. Does not reduce contamination	Difficult regulatory/community acceptance	Low capital, no O&M
	Monitoring	Groundwater Monitoring	Effective monitoring method	Easily implemented	Low capital, low O&M
		Vadose Zone Monitoring	Effective monitoring method	Easily implemented	Low capital, low O&M
Containment	Vertical Barriers	Slurry Wall	Effective. Reduces contaminant verticle migration	Easily implemented	Med capital, low O&M
		Synthetic Membrane Cutoff Wall	Effective. Reduces contaminant verticle migration	Easily implemented	Med-high capital, low O&M
	Horizontal Barriers	Asphalt-Based Cover	Effective. Reduces contaminant verticle migration	Implementable	Med capital, med O&M
		Compacted-Clay Cover	Effective. Reduces contaminant verticle migration	Implementable	Low capital, high O&M
		Multi-Layer Cover	Effective. Reduces percipitation infiltration and contaminant mobility	Difficult implementation	High capital, med O&M
		Vegetated Cover	Effective. Reduces percipitation infiltration and contaminant mobility	Easily implemented	Low capital, low O&M
In situ Treatment	Biological	Enhanced Bioremediation	Effective for some organic COCs in source areas, but not all.	Implementable	Med capital, low O&M
		 Pneumatic Fracturing	Not applicable to meet C/RAOs. This option is used to enhance other <i>in situ</i> processes	Easily implemented	Low capital, low O&M
	Chemical/Physical	Soil Gas Venting	Not completely effective for source area. May be effective for residual soil contamination	Easily implemented	Low capital, low O&M
		Soil Vapor Extraction	Moderately effective for VOCs	Easily implemented	Med capital, med O&M
		 Electrokinetics	Effectiveness and reliability evaluations require treatability study. Current work on Cr, Hg and U looks promising. Does not address COCs.	Difficult implementation. Has not been proven	Med capital, med O&M
		 Electroacoustical Soil Decontamination	Not effective	Implementable	Med capital, med O&M

LEGEND

 Technology or process option eliminated from further evaluation

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Figure 4.5 (Sheet 1 of 4)

Operable Unit No. 2  
Technical Memorandum No. 2  
Technology Evaluation for  
Subsurface Soils

(continued next page)

85

Subsurface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Removal	Solidification/Stabilization	Stabilization	Effective, reduces contaminant mobility	Implementable	Med capital, med O&M
		Cementation	Effective, reduces contaminant mobility	Implementable	Med capital, low O&M
		Vitrification	Effective, reduces contaminant mobility, off-gas treatment required	Difficult implementation	High capital, high initial O&M but no long-term O&M
	Thermal	Thermally Enhanced Soil Vapor Extraction	Effective for VOCs, off-gas treatment required	Implementable	Med capital, med O&M
	Excavation	Soil Excavation	Effective, contaminants are removed	Implementable	High capital, low O&M
	Short Distance Transport	Conveyor System	Effective, contaminants are removed. Would require controls to prevent mobilization of contaminants	Implementable	High capital, med O&M
		Truck Hauling	Effective, contaminants are removed. Would require controls to prevent mobilization of contaminants	Implementable	Low capital, low O&M
	Long Distance Transport	Truck/Rail Hauling	Effective, contaminants are removed. Would require controls to prevent mobilization of contaminants	Implementable, DOT permits may be required	Low capital, low O&M
	Offsite Storage/Disposal	Landfill/TSD Facility	Effective, reduces contaminant mobility	Easily implemented	High capital, low O&M
	Onsite Storage/Disposal	Disposal Vault	Effective, reduces contaminant mobility	Difficult implementation, would require permits and construction of onsite TSD facility	High capital, low O&M
		Container Storage	Effective, reduces contaminant mobility	Difficult implementation, RFETS has permitted storage areas; however, capacity may be limited. Long-term storage may not be acceptable	Low capital, med O&M
		Permitted Landfill	Effective, reduces contaminant mobility	Difficult implementation, would require permits, and construction of onsite TSD facility	High capital, med O&M

LEGEND

 Technology or process option eliminated from further evaluation

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Figure 4.5 (Sheet 2 of 4)

Operable Unit No. 2  
Technical Memorandum No. 2  
Technology Evaluation for  
Subsurface Soils

(continued next page)

Subsurface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Ex situ Treatment	Chemical/Physical	Chemical Red/Ox (1)	Effectiveness and reliability evaluations require treatability study. Current work at INEL looks promising	Insufficient data available to rate this process option	Insufficient data
		Soil Washing (2)	Effective, appears to meet C/RAOs. Would require controls to prevent mobilization of contaminants	Easily implemented after excavation	High capital, med O&M
		Solvent Extraction (3)	Effectiveness and reliability evaluations require treatability study. Current work on Ra, Th, and U looks promising	Implementability, TSD services for U may be applicable	High capital, med O&M
		Dehalogenation	Effective for VOCs	Difficult implementation in soils	Med capital, high O&M
		Soil Vapor Extraction	Effective for VOCs, off-gas treatment required	Easily implemented	Low capital, low O&M
		Electrokinetics	Not effective for COCs	Implementable	Med capital, med O&M
		Physical Separation (4)	Effectiveness and reliability evaluations require treatability study. Current work on Ra, and U looks promising	Implementable	Low capital, low O&M
		Magnetic Separation (5)	Appears effective and capable of meeting C/RAOs. Current work at INEL and RFP looks promising	Difficult implementation, innovative technology	Insufficient data
	Solidification/Stabilization	Stabilization (6)	Effectiveness and reliability evaluations require treatability study. Current work on heavy metals looks promising	Implementable after excavation	Insufficient data
		Encapsulation	Effective, appears to meet C/RAOs. Would require controls to prevent mobilization of contaminants	Easily implemented after excavation	Med capital, med O&M
		Cementation	Effective, appears to meet C/RAOs. Would require controls to prevent mobilization of contaminants	Easily implemented after excavation	Low capital, med O&M
		Vitrification: (Plasma Arc, Slagging Furnace, Joule-Heated, Glass Melter)	Effective, appears to meet C/RAOs. Would require controls to prevent mobilization of contaminants	Easily implemented after excavation	High capital, high O&M

(continued next page)

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Figure 4.5 (Sheet 3 of 4)

Operable Unit No. 2  
Technical Memorandum No. 2  
Technology Evaluation for  
Subsurface Soils

Subsurface Soil General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Ex situ Treatment	Thermal	Incineration: Fluidized Bed, Infrared, Molten Salt, Solar, Multiple Hearth, Microwave Melting, Molten Metal Reactor, Rotary Kiln, Oxygen-Enhanced, Liquid Injection, High Temperature Fluid Wall	Effective for VOCs. Would require controls to prevent mobilization of contaminants.	Implementable	High capital, high O&M
		Low-Temperature Thermal Desorption	Effective for VOCs. Would require controls to prevent mobilization of contaminants.	Implementable	Med capital, med O&M
		HTS Thermal Distillation Process	Effective for VOCs. Would require controls to prevent mobilization of contaminants.	Implementable	Med capital, med O&M
		Pyrolysis	Effective for VOCs. Would require controls to prevent mobilization of contaminants.	Implementable	Med capital, med O&M

NOTE: Process options are components of the following treatment systems or studies:

- |   |   |
|---|---|
| (1) Aqueous Biphasic Separation (ABS)               | (4) Aqueous Biphasic Separation (ABS)               |
| (2) TRU Clean®                                      | Surfactant Enhanced Remediation                     |
| Surfactant Enhanced Remediation                     | Air Sparged Hydrocyclone (ASH)                      |
| Gravity/Floatation/Chemical Enhancement (NRT Study) | TRU Clean®  |
| Aqueous Biphasic Separation                         | Gravity/Floatation/Chemical Enhancement (NRT Study) |
| Chemically Enhanced Steam Stripping (CESS)          | (5) High Gradient Magnetic Separation (HGMS)        |
| Chelating Aquants (LANL Study)                      | (6) WES-PHIX Process                                |
| (3) CEPOD Process (PNL)                             |   |
| B.E.S.T. Process                                    |   |

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Figure 4.5 (Sheet 4 of 4)

Operable Unit No. 2  
Technical Memorandum No. 2  
Technology Evaluation for  
Subsurface Soils

Groundwater General Response Action		Remedial Technology	Process Options	Effectiveness	Implementability	Cost
<p>No Further Action</p> <p>Intrinsic Remediation</p> <p>Groundwater Monitoring</p> <p>Effective for VOCs; reduces toxicity</p>	<p>Access Restrictions</p> <p>Fencing, Security</p> <p>Lock Out/Tag Out Walls</p> <p>Deed Restrictions</p> <p>Zoning Restrictions</p> <p>Regulatory Restrictions</p> <p>Groundwater Monitoring</p>	<p>Land Use Restrictions</p> <p>Effective for VOCs and radionuclides; reduces exposure</p> <p>Effective for VOCs and radionuclides; reduces exposure</p> <p>Effective for VOCs and radionuclides; reduces exposure</p> <p>Effective for VOCs and radionuclides; reduces exposure</p> <p>Effective for VOCs and radionuclides; reduces exposure</p> <p>Effective for VOCs and radionuclides; reduces exposure</p> <p>Effective for VOCs and radionuclides; reduces exposure</p>	<p>Intrinsic Remediation</p> <p>Effective for VOCs; reduces toxicity</p>	<p>Low capital; low O&amp;M</p> <p>Low capital; negligible O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p>	<p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p>	<p>Low capital; low O&amp;M</p> <p>Low capital; negligible O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p>
<p>Containment</p> <p>Surface Water Controls</p> <p>Enhanced Soil Cap, Revegetation, Grading, and Compaction</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Groundwater Controls</p> <p>Interceptor Trenches and Local Extraction Wells</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Vertical Barriers</p> <p>Sheet Piling</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Slurry Wall</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Synthetic Membrane Cutoff Wall</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Asphalt-Type Cover</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Compacted Clay Cover</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Horizontal Barriers</p> <p>Multi-Layer Cover</p> <p>Effective for VOCs and radionuclides; reduces mobility</p>	<p>Surface Water Controls</p> <p>Enhanced Soil Cap, Revegetation, Grading, and Compaction</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Groundwater Controls</p> <p>Interceptor Trenches and Local Extraction Wells</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Vertical Barriers</p> <p>Sheet Piling</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Slurry Wall</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Synthetic Membrane Cutoff Wall</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Asphalt-Type Cover</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Compacted Clay Cover</p> <p>Effective for VOCs and radionuclides; reduces mobility</p> <p>Horizontal Barriers</p> <p>Multi-Layer Cover</p> <p>Effective for VOCs and radionuclides; reduces mobility</p>	<p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Moderate capital; low O&amp;M</p> <p>Moderate capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p>	<p>Easily implemented</p> <p>Easily implemented</p> <p>Difficult to implement</p> <p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p> <p>Easily implemented</p>	<p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Moderate capital; low O&amp;M</p> <p>Moderate capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p>	<p>High capital; moderate O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Moderate capital; low O&amp;M</p> <p>Moderate capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p> <p>Low capital; low O&amp;M</p>	<p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p> <p>Low capital; no O&amp;M</p>

(Continued next page)

Figure 4.8 (Sheet 1 of 2)

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GOLDEN, COLORADO

Operable Unit No. 2  
Technical Memorandum No. 2  
Technology Evaluation  
for Groundwater

Groundwater General Response Action	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
Removal	Groundwater Extraction	Interceptor Trenches and Local Extraction Wells	Effective for VOCs and radionuclides; reduces mobility and volume	Easily implemented	Low capital; low O&M
	Groundwater Transport	Truck/Rail Hauling Pipeline			
	Disposal	RFETS STP			
In Situ Treatment	Enhanced Bioremediation	Enhancement of aerobic or anaerobic conditions, comatabolic substrates	Effective for VOCs; reduces toxicity	Insufficient data	Low capital; low O&M
	Chemical/Physical	Air Sparging	Effective for VOCs; reduces toxicity	Easily implemented	Low capital; low O&M
	Thermal	Passive Treatment Wall	Effective for VOCs and radionuclides; reduces toxicity	Insufficient data; pilot scale technology	Moderate capital; low O&M
		T-SVE			
Ex Situ Treatment	Chemical/Physical	Onsite Water Treatment Plant	Effective for VOCs and radionuclides; reduces toxicity	Easily implemented	Low capital; low O&M

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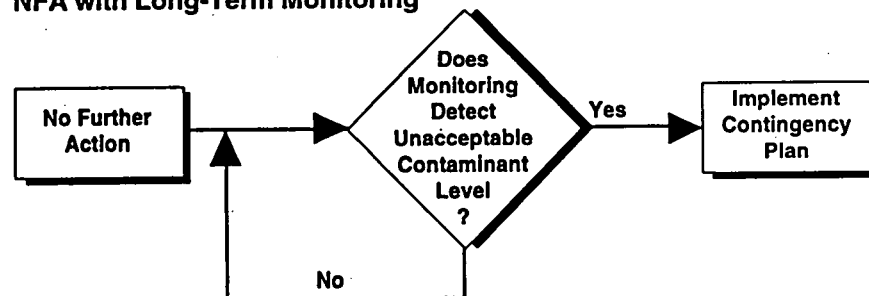
Figure 4.8 (Sheet 2 of 2)

Operable Unit No. 2  
Technical Memorandum No. 2  
Technology Evaluation  
for Groundwater

**Surface Soil Source/No Further Action**

**Alternative 1:**

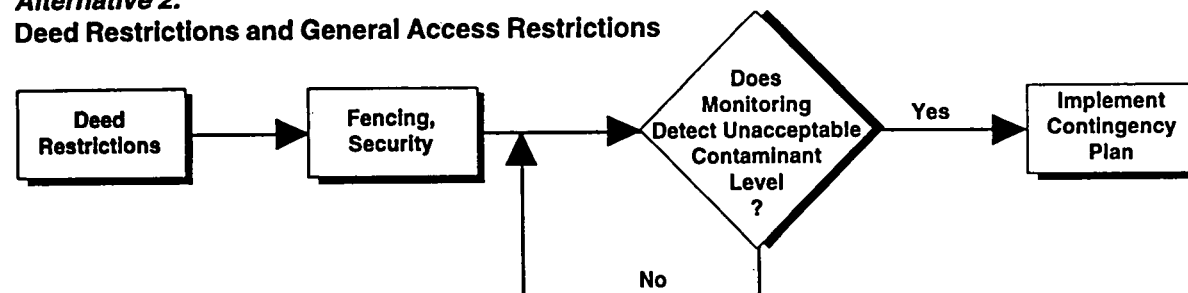
**NFA with Long-Term Monitoring**



**Surface Soil Source/Institutional Controls**

**Alternative 2:**

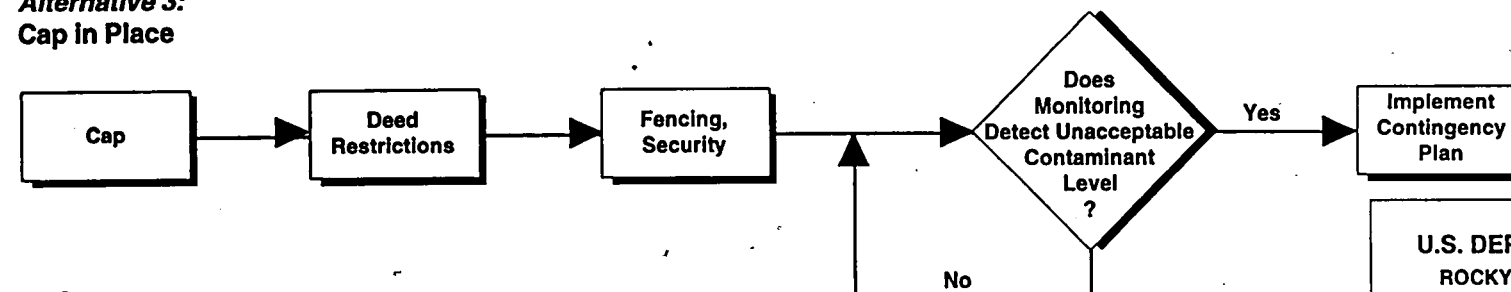
**Deed Restrictions and General Access Restrictions**



**Surface Soil Source/Containment**

**Alternative 3:**

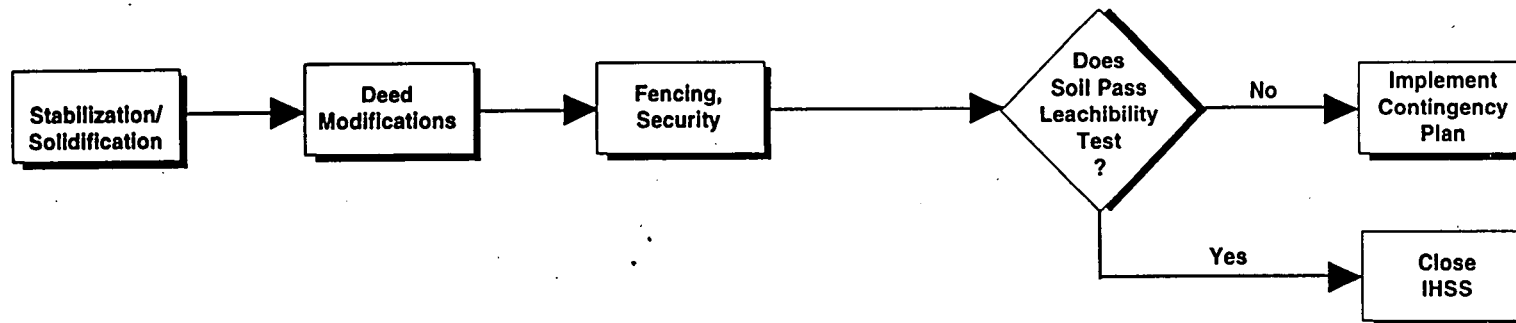
**Cap in Place**



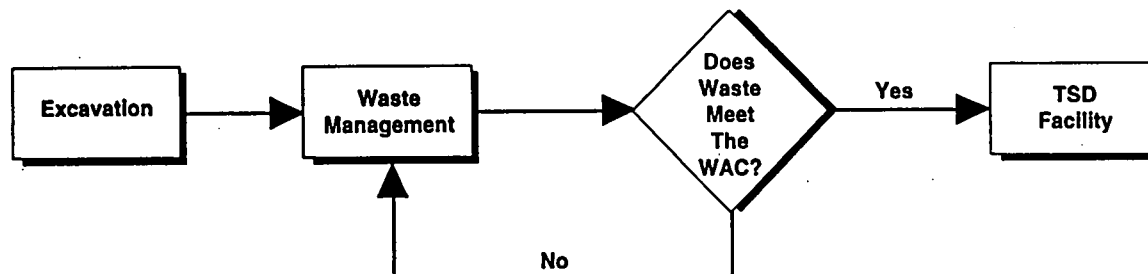
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GOLDEN, COLORADO

Figure 5.1  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Surface Soil Source Area  
(Radionuclides)

**Surface Soil Source/*In Situ* Treatment**  
**Alternative 4:**  
***In Situ* Stabilization**



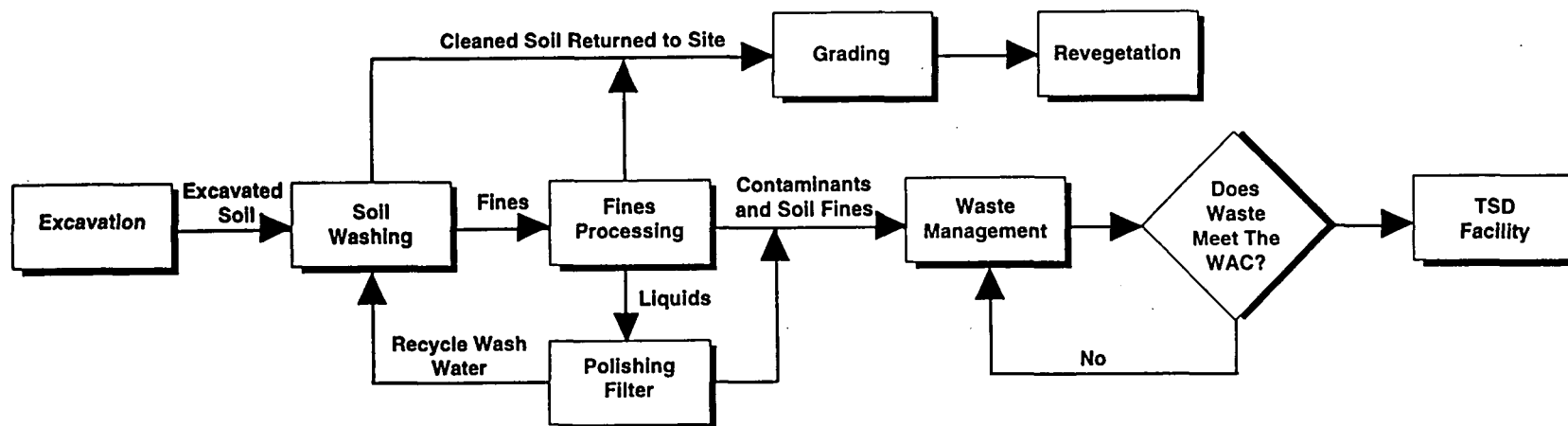
**Surface Soil Source/Removal**  
**Alternative 5:**  
**Excavation and Disposal**



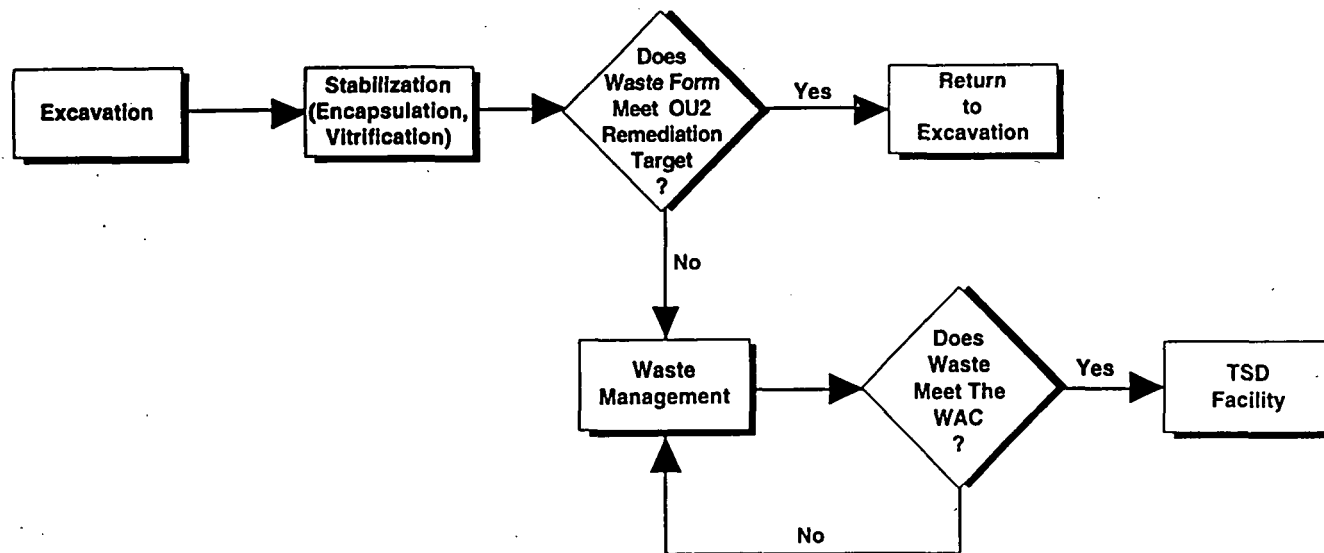
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Figure 5.2  
 Operable Unit No. 2  
 Technical Memorandum No. 2  
 OU2 Surface Soil Source Area  
 (Radionuclides)

**Surface Soil Source/Ex Situ Treatment**  
**Alternative 6:**  
**Excavation and Soil Washing**



**Surface Soil Source/Ex Situ Treatment**  
**Alternative 7:**  
**Excavation, Ex Situ Stabilization, and Return to Excavation**



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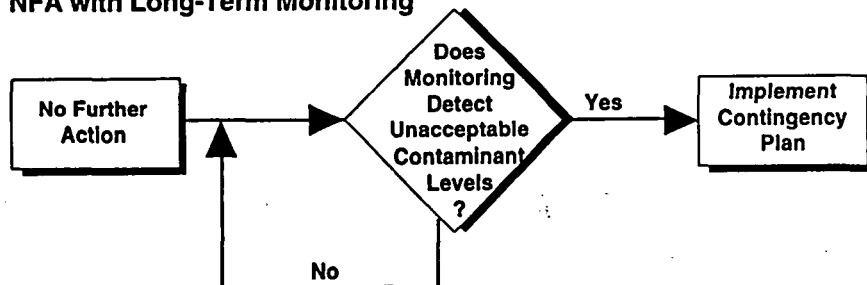
Figure 5.3  
 Operable Unit No. 2  
 Technical Memorandum No. 2  
 OU2 Surface Soil Source Area  
 (Radionuclides)

93

**Subsurface Soil Source/No Further Action**

**Alternative 1:**

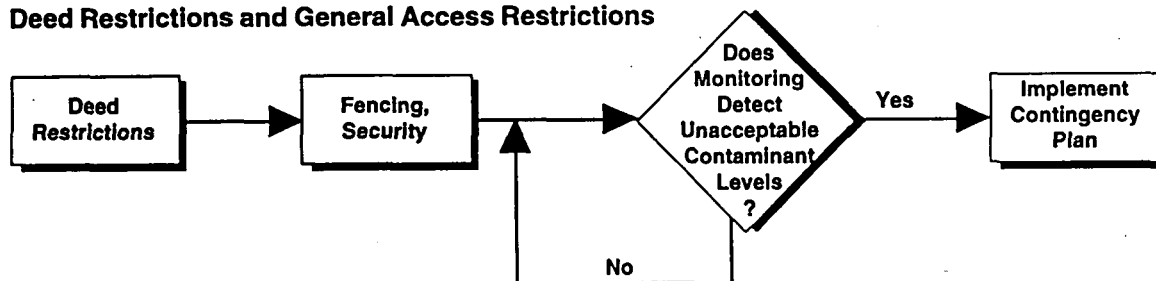
**NFA with Long-Term Monitoring**



**Subsurface Soil Source/Institutional Controls**

**Alternative 2:**

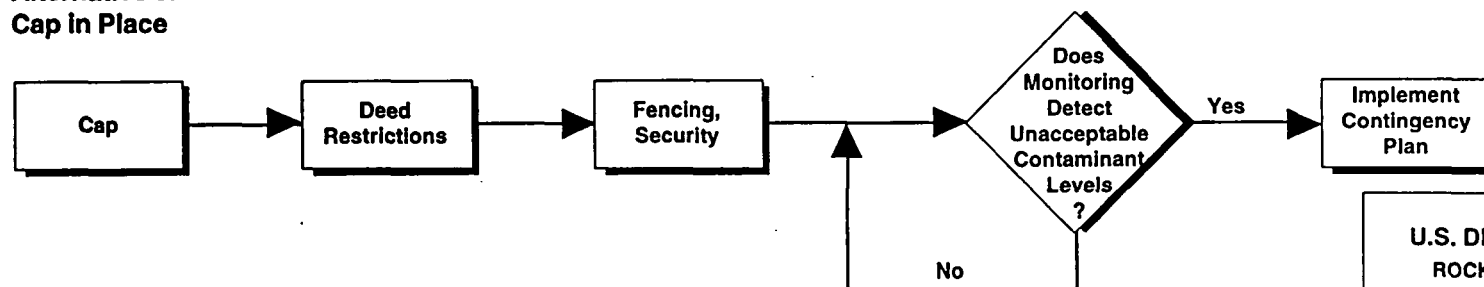
**Deed Restrictions and General Access Restrictions**



**Subsurface Soil Source/Containment**

**Alternative 3:**

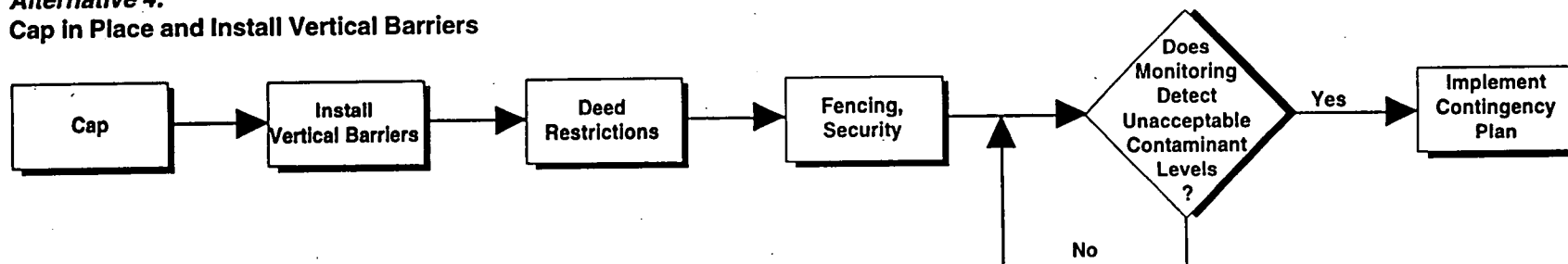
**Cap in Place**



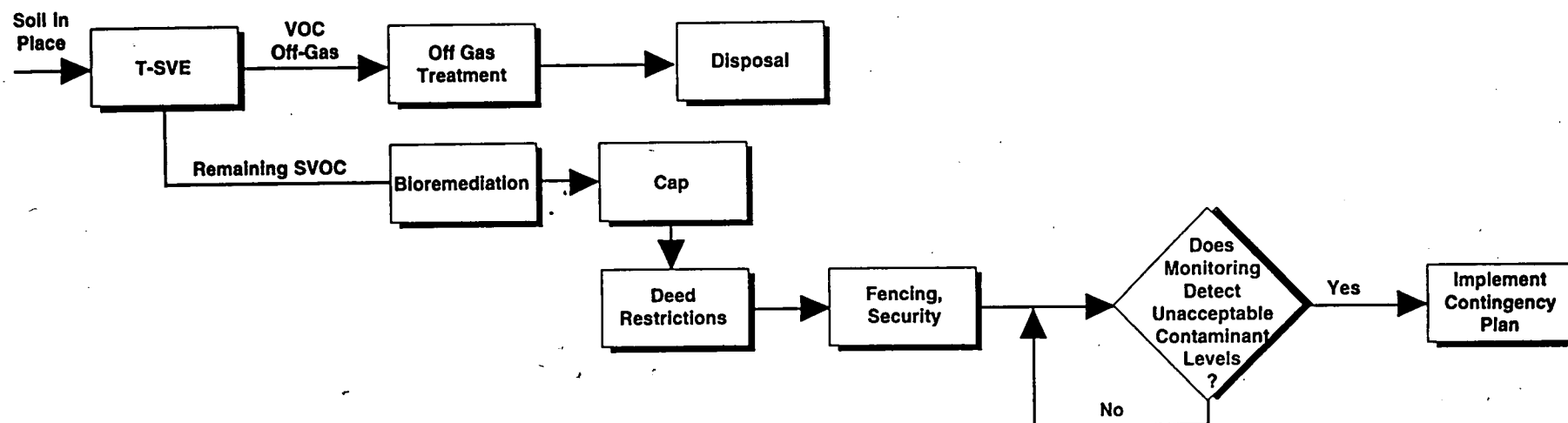
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GOLDEN, COLORADO

Figure 5.4  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Subsurface Soil Source Area  
(Radionuclides, Heavy Metals and Organics)

**Subsurface Soil Source/Containment**  
**Alternative 4:**  
**Cap in Place and Install Vertical Barriers**



**Subsurface Soil Source/In Situ Treatment**  
**Alternative 5:**  
**Thermally Enhanced Soil Vapor Extraction, Enhanced Bioremediation, and Cap**



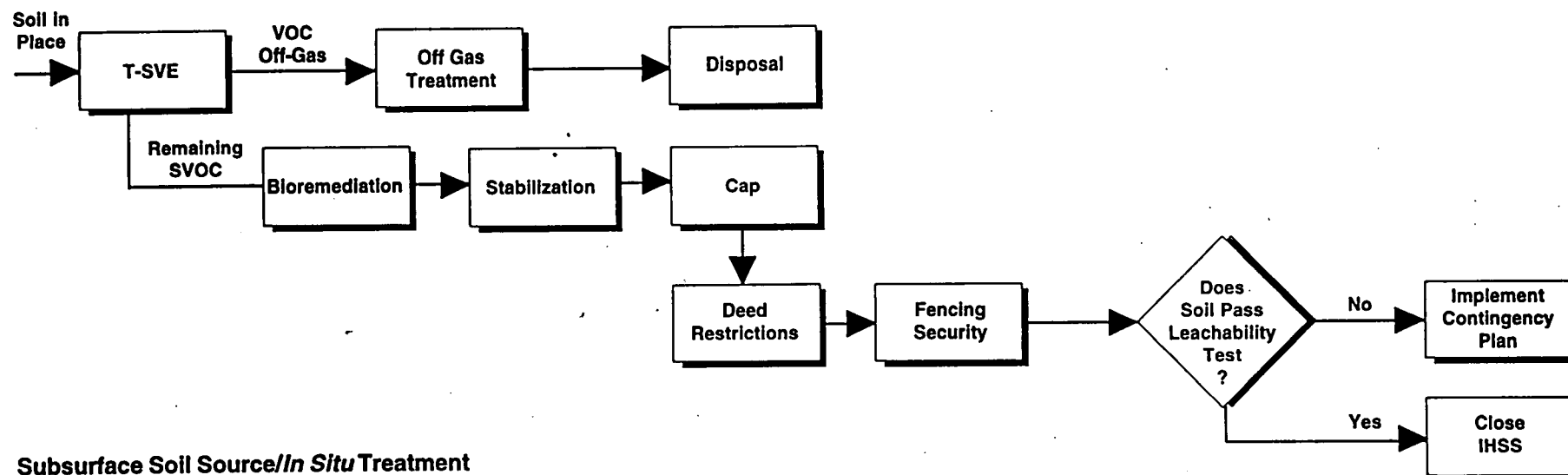
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Figure 5.5  
 Operable Unit No. 2  
 Technical Memorandum No. 2  
 OU2 Subsurface Soil Source Area  
 (Radionuclides, Heavy Metals and Organics)

# Subsurface Soil Source/*In Situ* Treatment

## Alternative 6:

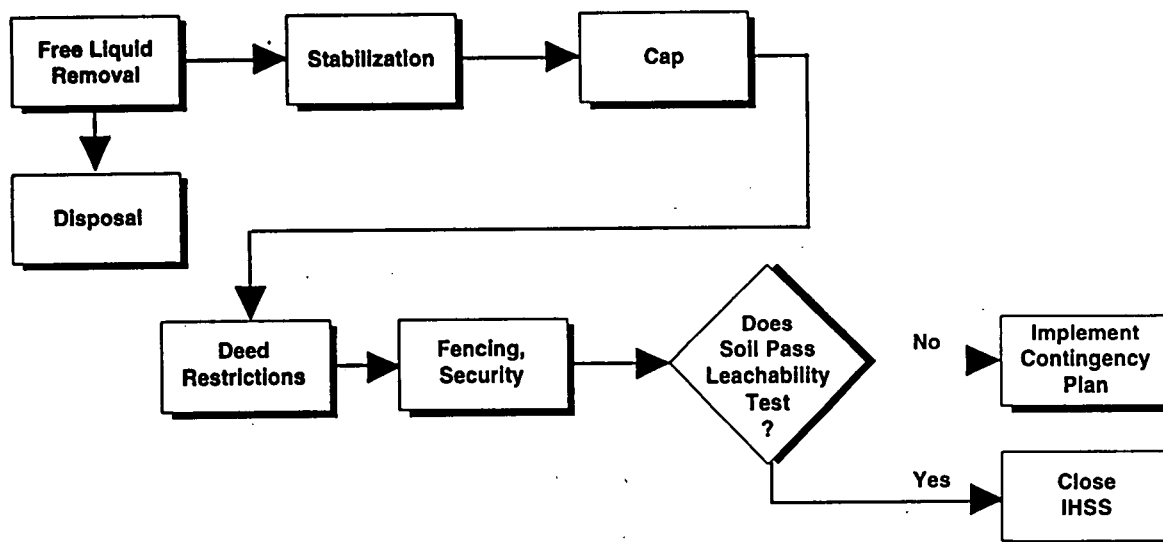
Thermally Enhanced Soil Vapor Extraction, Enhanced Bioremediation, Stabilization, and Cap



# Subsurface Soil Source/*In Situ* Treatment

## Alternative 7:

Free Liquid Removal, Stabilization, and Cap

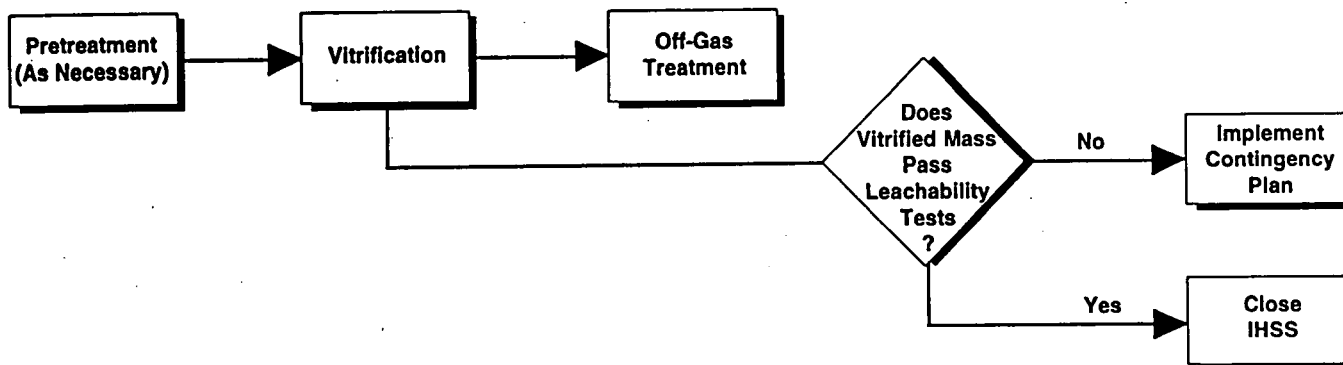


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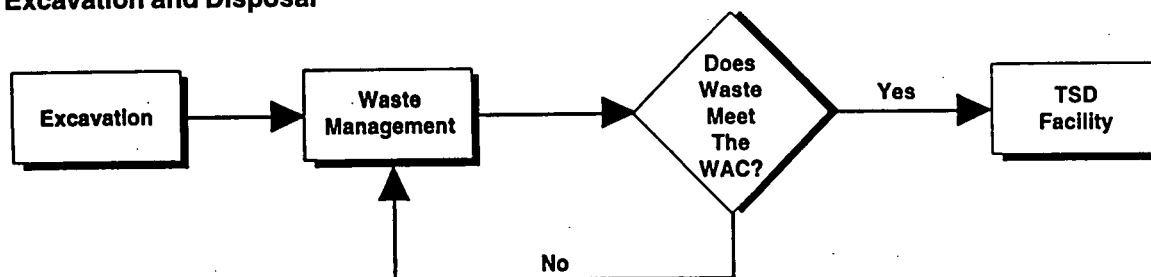
Figure 5.6  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Subsurface Soil Source Area  
(Radionuclides, Heavy Metals and Organics)

96

**Subsurface Soil Source/*In Situ* Treatment**  
**Alternative 8:**  
***In Situ* Vitrification (With Pretreatment as Necessary)**



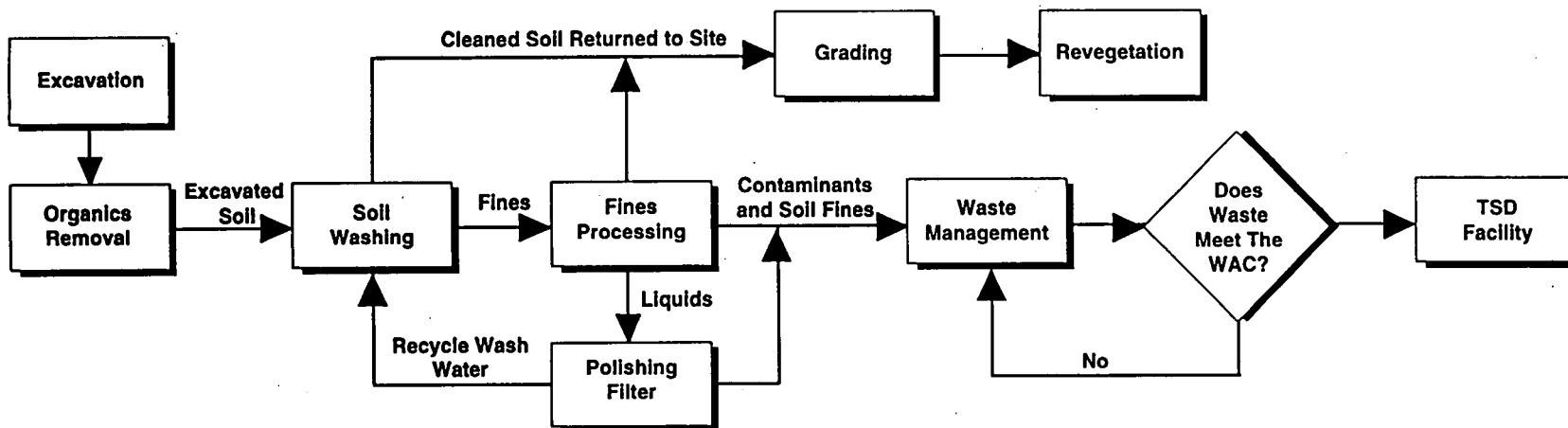
**Subsurface Soil Source/Removal**  
**Alternative 9:**  
**Excavation and Disposal**



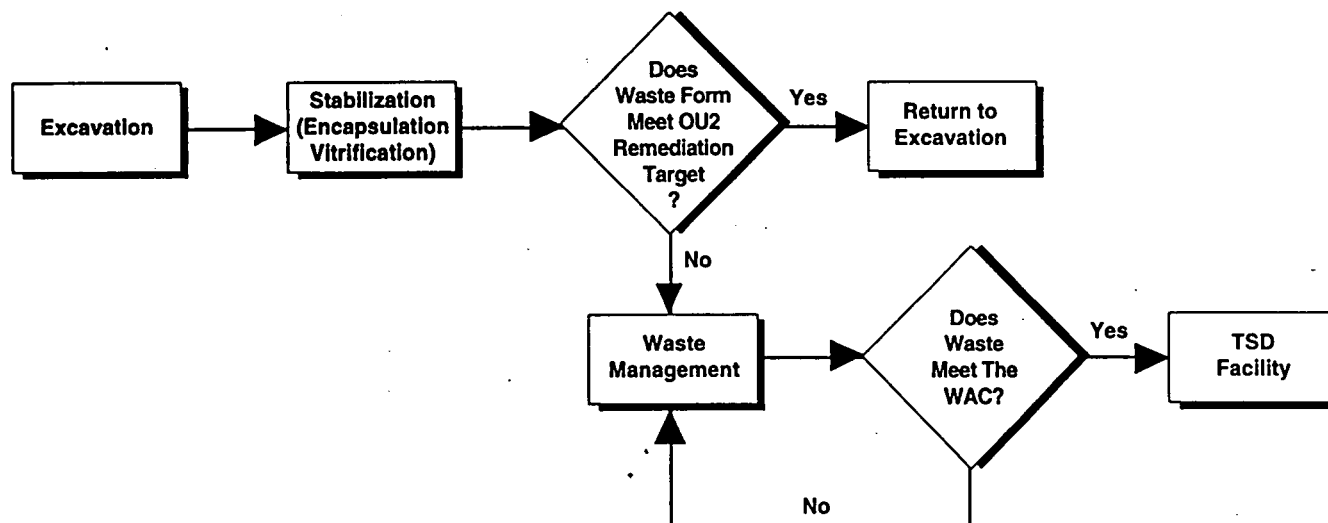
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Figure 5.7  
 Operable Unit No. 2  
 Technical Memorandum No. 2  
 OU2 Subsurface Soil Source Area  
 (Radionuclides, Heavy Metals and Organics)

**Subsurface Soil Source/Ex Situ Treatment**  
**Alternative 10:**  
**Excavation, Organics Removal, and Soil Washing**



**Subsurface Soil Source/Ex Situ Treatment**  
**Alternative 11:**  
**Excavation, Ex Situ Stabilization, and Return to Excavation**



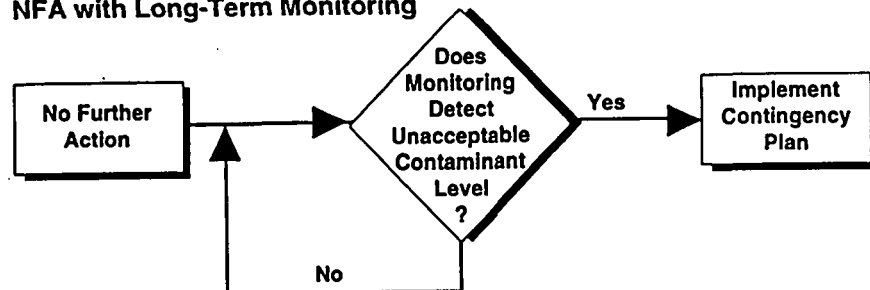
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Figure 5.8  
 Operable Unit No. 2  
 Technical Memorandum No. 2  
 OU2 Subsurface Soil Source Area  
 (Radionuclides, Heavy Metals and Organics)

**Surface Soil Residual/No Further Action**

**Alternative :1**

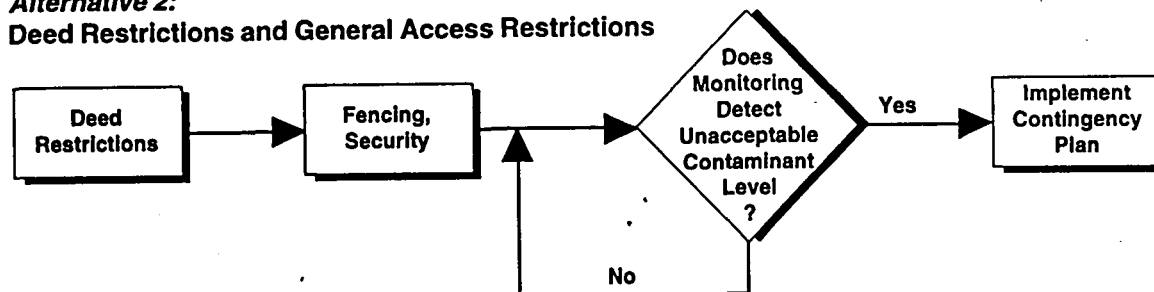
**NFA with Long-Term Monitoring**



**Surface Soil Residual/Institutional Controls**

**Alternative 2:**

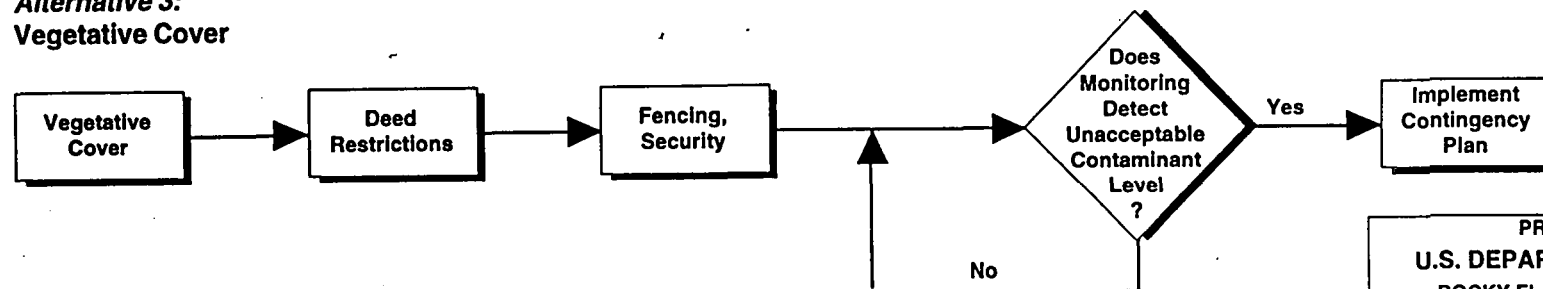
**Deed Restrictions and General Access Restrictions**



**Surface Soil Residual/Containment**

**Alternative 3:**

**Vegetative Cover**



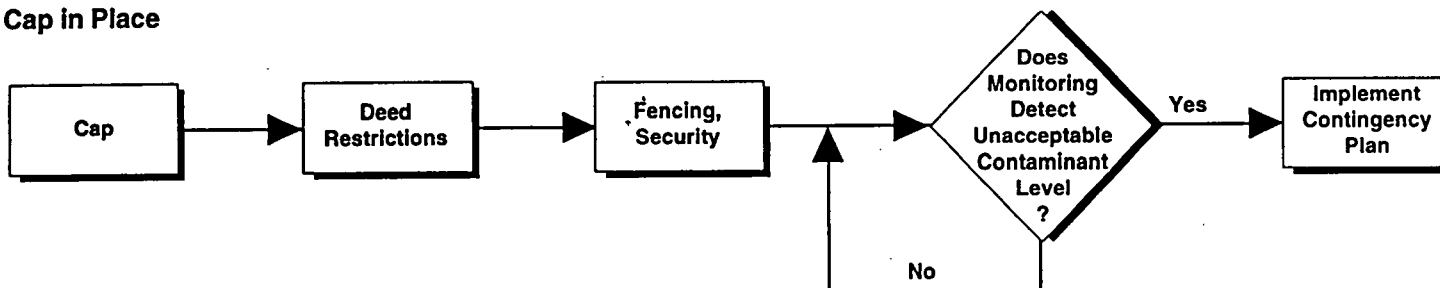
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GOLDEN, COLORADO

Figure 5.9  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Surface Soil Residual Contamination Area  
(Radionuclides)

**Surface Soil Residual/Containment**

**Alternative 4:**

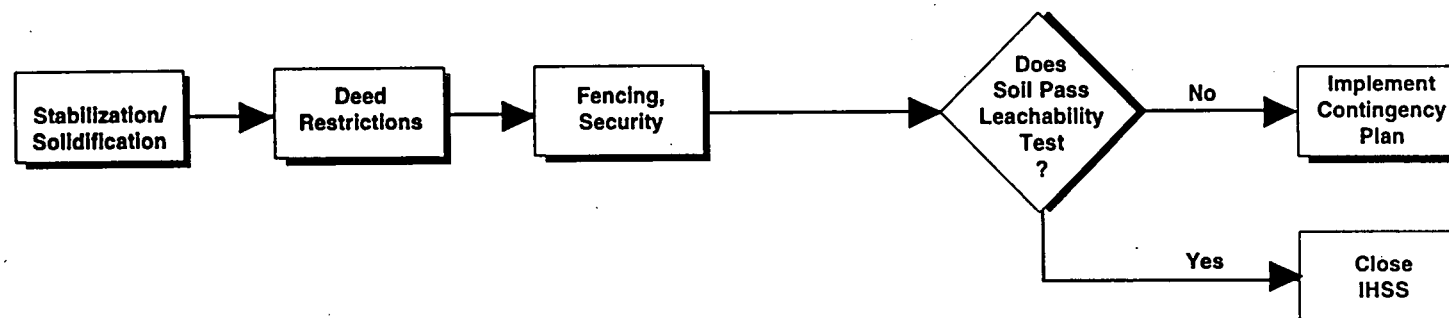
**Cap in Place**



**Surface Soil Residual/In-Situ Treatment**

**Alternative 5:**

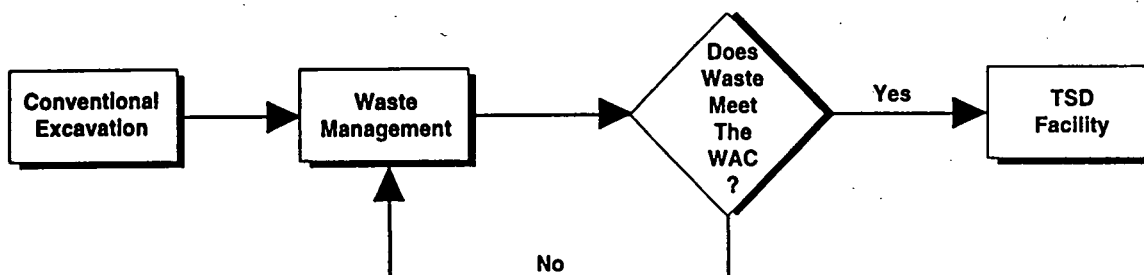
**In Situ Stabilization/Solidification**



**Surface Soil Residual/Removal**

**Alternative 6:**

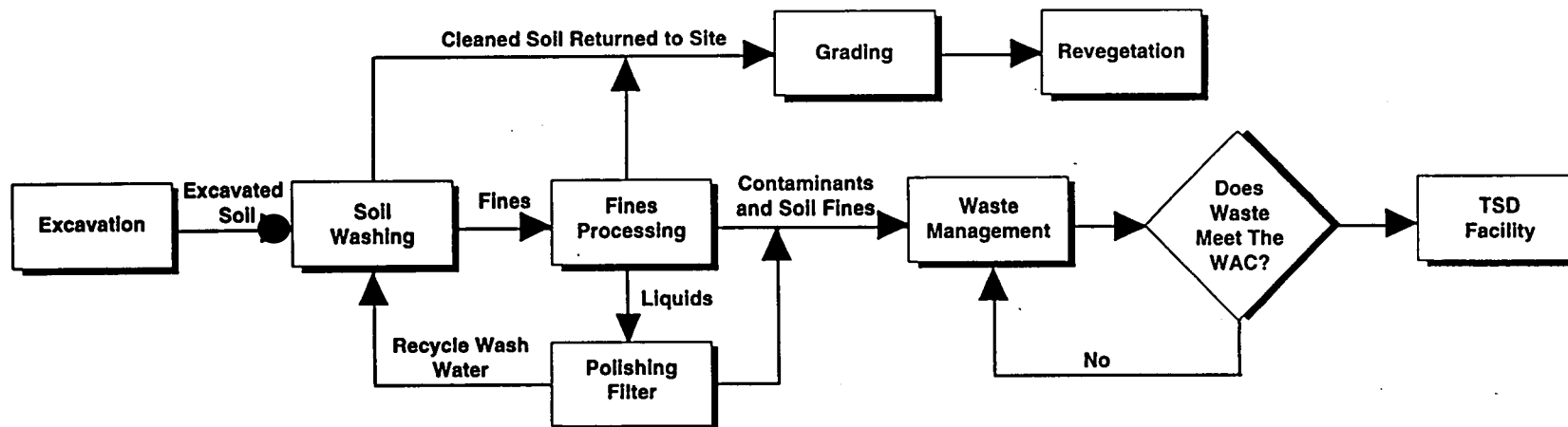
**Excavation and Disposal**



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Figure 5.10  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Surface Soil Residual Contamination Area  
(Radionuclides)

**Surface Soil Residual/Ex Situ Treatment**  
**Alternative 7:**  
**Excavation and Soil Washing**



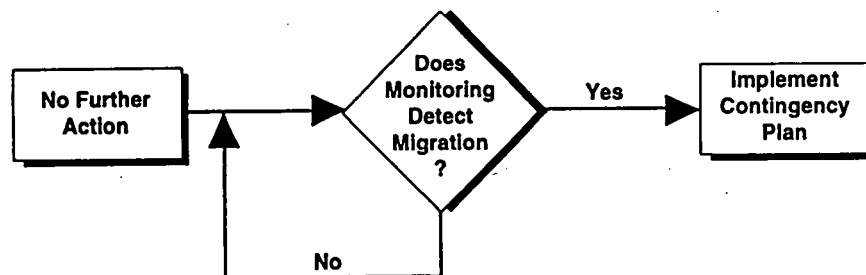
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Figure 5.11  
 Operable Unit No. 2  
 Technical Memorandum No. 2  
 OU2 Surface Soil Residual Contamination Area  
 (Radionuclides)

**Subsurface Soil Residual/No Further Action**

**Alternative 1:**

**NFA with Long-Term Monitoring**



**Subsubsurface Soil Residual/*In Situ* Treatment**

**Alternative 2:**

**Soil Vapor Extraction (Ambient or Thermally Enhanced)**

(Presumptive Remedy)



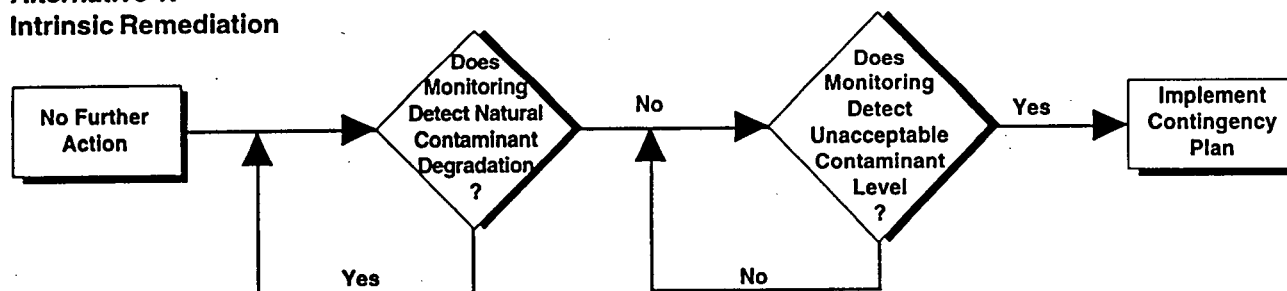
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GOLDEN, COLORADO

Figure 5.12  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Subsurface Soil Residual Contamination Area  
(Radionuclides and VOCs)

### Groundwater Contamination/No Further Action

#### Alternative 1:

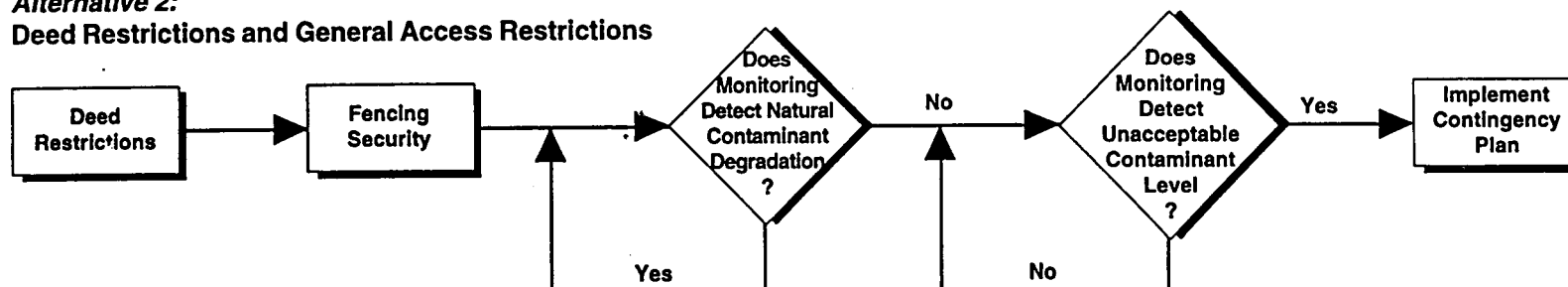
#### Intrinsic Remediation



### Groundwater Contamination/Institutional Controls

#### Alternative 2:

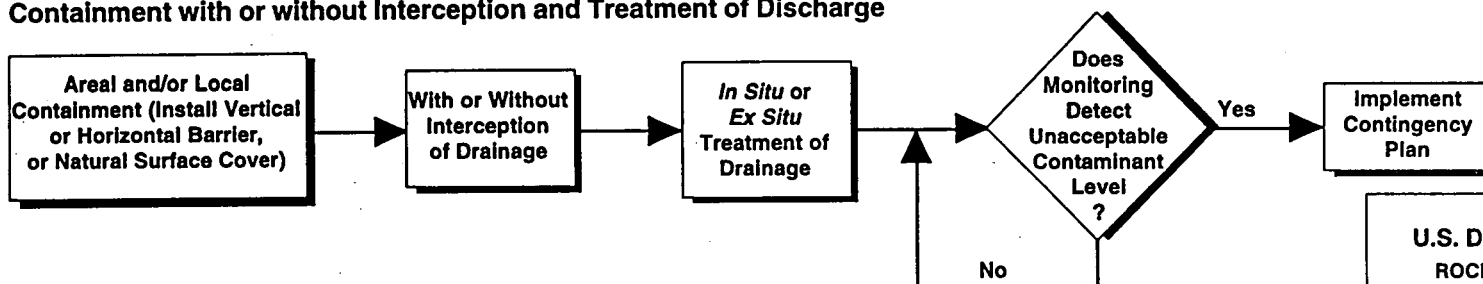
#### Deed Restrictions and General Access Restrictions



### Groundwater Contamination/Containment

#### Alternative 3:

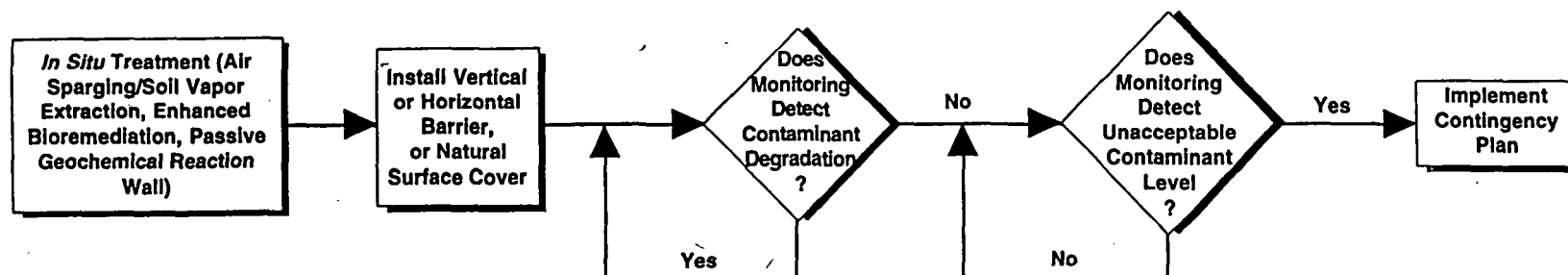
#### Containment with or without Interception and Treatment of Discharge



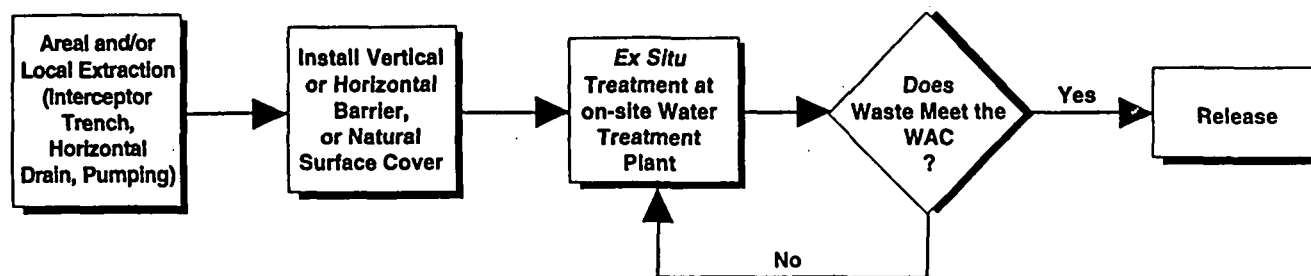
PREPARED FOR  
U.S. DEPARTMENT OF ENERGY  
ROCKY FLATS ENVIRONMENTAL  
TECHNOLOGY SITE  
GOLDEN, COLORADO

Figure 5.13  
Operable Unit No. 2  
Technical Memorandum No. 2  
OU2 Groundwater Contamination Area  
(Radionuclides and VOCs)

**Groundwater Contamination/*In Situ* Treatment**  
**Alternative 4:**  
***In Situ* Treatment with or without Containment**



**Groundwater Contamination/*Ex Situ* Treatment**  
**Alternative 5:**  
**Extraction with or without Containment, *Ex Situ* Treatment, and Release**



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 TECHNOLOGY SITE  
 GOLDEN, COLORADO

Figure 5.14  
 Operable Unit No. 2  
 Technical Memorandum No. 2  
 OU2 Groundwater Contamination Area  
 (Radionuclides and VOCs)

## TABLES

TABLE 1.1  
OU2 Remedial Alternatives Development Matrix

General Response Actions	Remediation Areas				
	Surface Soil Source	Subsurface Soil Source	Surface Soil Residual	Subsurface Soil Residual	UHSU Ground Water
No Further Action	a) No further action with long-term monitoring	a) No further action with long-term monitoring	a) No further action with long-term monitoring	a) No further action with long-term monitoring	a) No further action with long-term monitoring
Institutional Controls	a) Deed restrictions and general access restrictions	a) Deed restrictions and general access restrictions	a) Deed restrictions and general access restrictions	a) Deed restrictions and general access restrictions	a) Deed restrictions and general access restrictions
Containment	a) Cap in place	a) Cap in place b) Cap in place and install Barrier walls	a) Vegetative cover b) Cap in place	a) Cap in place	a) Barrier walls (only) b) Barrier walls (with localized dewatering)
<i>In Situ</i> Treatment	a) <i>In Situ</i> stabilization	a) Thermally enhanced soil vapor extraction, enhanced bioremediation, and cap b) Thermally enhanced soil vapor extraction, enhanced bioremediation, stabilization, and cap. c) Free liquid removal, <i>in situ</i> stabilization, cap d) <i>In situ</i> vitrification (with pretreatment as necessary)	a) <i>In Situ</i> stabilization	a) Enhanced bioremediation b) Soil vapor extraction (ambient or thermally enhanced)	a) Enhanced bioremediation b) Air sparging c) Reactive walls
Removal	a) Excavation and disposal <sup>a</sup>	a) Excavation and disposal <sup>a</sup>	a) Excavation and disposal <sup>a</sup>	N/A	a) Collection and disposal a) Extraction (dewatering) and disposal
<i>Ex Situ</i> Treatment	a) Excavation and soil washing <sup>b</sup> b) Excavation, <i>ex situ</i> stabilization, and return to excavation	a) Excavation, organics removal, and soil washing <sup>b</sup> b) Excavation, <i>ex situ</i> stabilization, and return to excavation	a) Excavation and soil washing <sup>b</sup>	N/A	a) Extraction, treatment, and re-injection

<sup>a</sup> Disposal includes the evaluation of on-site disposal and off-site disposal options (including treatment to meet waste acceptance criteria)

<sup>b</sup> Soils washing includes: soils separation; clean soil return; fines processing; waste management and disposal<sup>a</sup>

**TABLE 2.1**  
**IHSSs ASSOCIATED WITH OU2**

IHSS	OU2 REMEDIATION AREAS <sup>a/</sup>			
	SOURCE AREAS FOR SURFACE SOIL CONTAMINATION	SOURCE AREAS FOR SUBSURFACE SOIL CONTAMINATION	RESIDUAL SURFACE SOIL CONTAMINATION	RESIDUAL SUBSURFACE SOIL CONTAMINATION
903 Pad Drum Storage Site (112)		X		X
903 Pad Lip Site (155)	X		X	X
East Spray Fields (216.2)			X	
East Spray Field (216.3)			X	
Gas Detoxification Site (183)			X	
Mound Site (113)		X	X	X
Oil Burn Pit No. 2 Site (153)			X	
Pallet Burn Site (154)			X	
Reactive Metal Destruction Site (140)			X	
Trench T-1 (108)		X	X	X
Trench T-2 (109)		X	X	X
Trench T-3 (110)		X	X	X
Trench T-4 (111.1)		X	X	X
Trench T-5 (111.2)		X	X	X
Trench T-6 (111.3)		X	X	X
Trench T-7 (111.4)		X	X	X
Trench T-8 (111.5)		X	X	X
Trench T-9 (111.6)		X	X	X
Trench T-10 (111.7)		X	X	X
Trench T-11 (111.8)		X	X	X
Trench T-12		X	X	X
Trench T-13		X	X	X

<sup>a/</sup> Groundwater contamination in the UHSU occurs throughout OU2 and is non-IHSS specific.

**TABLE 2.5**  
**IHSSs THAT CONTAIN CONTAMINANTS OF CONCERN**  
**GREATER THAN SELECTED REMEDIATION TARGETS**

IHSS	OU2 REMEDIATION AREAS <sup>a/</sup>			
	SOURCE AREAS FOR SURFACE SOIL CONTAMINATION	SOURCE AREAS FOR SUBSURFACE SOIL CONTAMINATION	RESIDUAL SURFACE SOIL CONTAMINATION	RESIDUAL SUBSURFACE SOIL CONTAMINATION
903 Pad Drum Storage Site (112)		X		
903 Pad Lip Site (155)	X		X <sup>b/</sup>	
East Spray Fields (216.2)				
East Spray Field (216.3)				
Gas Detoxification Site (183)				
Mound Site (113)		X		
Oil Burn Pit No. 2 Site (153)				
Pallet Burn Site (154)				
Reactive Metal Destruction Site (140)				
Trench T-1 (108)		X		
Trench T-2 (109)		X		
Trench T-3 (110)		X		X
Trench T-4 (111.1)		X		
Trench T-5 (111.2)		X		
Trench T-6 (111.3)		X		
Trench T-7 (111.4)		X		
Trench T-8 (111.5)		X		
Trench T-9 (111.6)		X		
Trench T-10 (111.7)		X		
Trench T-11 (111.8)		X		
Trench T-12		X		
Trench T-13		X		

<sup>a/</sup> Groundwater contamination in the UHSU occurs throughout OU2 and is non-IHSS specific.

<sup>b/</sup> Includes surrounding areas of the IHSS with concentrations of contamination that exceed OU2 remediation target level.

**TABLE 4.1**  
**SELECTED REPRESENTATIVE PROCESS OPTIONS**  
**FOR SURFACE SOILS**

<u>SURFACE SOIL GENERAL RESPONSE ACTION</u>	<u>REMEDIAL TECHNOLOGY</u>	<u>REPRESENTATIVE PROCESS OPTION</u>
No Further Action (NFA)	None	Not Applicable
Institutional Actions	Access Restrictions Land Use Restrictions Monitoring	Fencing, Security, Etc. Deed Restrictions Fugitive Dust Monitoring
Containment	Horizontal Barriers	Cover
Removal	Excavation	Soil Excavation
	Short Distance Transport Long Distance Transport	Conveyor System Truck/Rail Hauling
	Offsite Disposal Onsite Disposal	Landfill/TSD Facility Permitted Landfill
<i>In Situ</i> Treatment	Solidification/Stabilization	Solidification/Stabilization
<i>Ex Situ</i> Treatment	Chemical/Physical Treatment Solidification/Stabilization	Soil Washing Stabilization Vitrification

**TABLE 4.2**  
**SELECTED REPRESENTATIVE PROCESS OPTIONS**  
**FOR SUBSURFACE SOILS**

<b>SUBSURFACE SOIL GENERAL RESPONSE ACTION</b>	<b>REMEDIAL TECHNOLOGY</b>	<b>REPRESENTATIVE PROCESS OPTION</b>
No Further Action (NFA)	None	Not Applicable
Institutional Controls	Access Restrictions Land Use Restrictions Monitoring	Fencing, Security, Etc. Deed Restrictions Vadose Zone Monitoring
Containment	Vertical Barriers Horizontal Barriers	Slurry Wall Cover
Removal	Mechanical Excavation	Soil Excavation
	Short Distance Transport Long Distance Transport	Conveyer System Truck/Rail Hauling
	Offsite Disposal Onsite Disposal	Landfill/TSD Facility Permitted Landfill
<i>In Situ</i> Treatment	Biological Chemical/Physical Treatment Solidification/Stabilization	Enhanced Bioremediation Soil Vapor Extraction Stabilization Vitrification
	Thermal Treatment	Thermally Enhanced Soil Vapor Extraction
<i>Ex Situ</i> Treatment	Chemical/Physical Treatment Solidification/Stabilization	Soil Washing Encapsulation Vitrification
	Thermal Treatment	Low-Temperature Thermal Desorption Incineration

**TABLE 4.3**  
**SELECTED REPRESENTATIVE PROCESS OPTIONS**  
**FOR GROUNDWATER**

<u>GROUNDWATER GENERAL RESPONSE ACTION</u>	<u>REMEDIAL TECHNOLOGY</u>	<u>REPRESENTATIVE PROCESS OPTION</u>
No Further Action (NFA)	Intrinsic Remediation	Groundwater Monitoring
Institutional Controls	Access Controls Land Use Restrictions Intrinsic Remediation	Fencing, Security, Etc. Deed Restrictions Groundwater Monitoring
Containment	Surface Controls Groundwater Controls Vertical Barriers Horizontal Barriers	Revegetation Interceptor Trenches Cutoff Wall Cover
Removal	Groundwater Extraction Groundwater Transport Disposal	Interceptor Trenches Truck/Rail Hauling RFETS Sewage Treatment Plant
<i>In Situ</i> Treatment	Enhanced Bioremediation  Chemical/Physical Treatment  Thermal	Enhanced Aerobic Bioremediation Enhanced Anaerobic Bioremediation Air Sparging/SVE Passive Treatment Wall  Thermally Enhanced Soil Vapor Extraction
<i>Ex Situ</i> Treatment	Chemical/Physical Treatment	Onsite Water Treatment Plant

811

TABLE 6.1  
POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR  
SOURCE AREAS FOR SURFACE SOIL CONTAMINATION

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE						
		NFA	Institutional Controls	Cap in Place	<i>In Situ</i> Stabilization/ Solidification	Excavate, Dispose	Excavate, Soil Washing	Excavate, <i>Ex Situ</i> Solidification/ Stabilization, Return
16 USC §§ 469 and 470 36 CFR 65, 296, and 800 43 CFR 3 and 7 CRS 24-80-401 to 410	Historic and Archeological Preservation <sup>a/</sup>	X	X	X	X	X	X	X
16 USC § 661 et seq.	Fish and Wildlife Coordination Act	X	X	X	X	X	X	X
16 USC § 668	Eagle Protection Acts	X	X	X	X	X	X	X
16 USC § 701-715 50 CFR 10	Migratory Bird Treaty	X	X	X	X	X	X	X
16 USC § 1531 50 CFR 402 CRS 33-2-101 to 33-2-107	Evaluate Federal Projects for Potential Impact to Endangered or Threatened Species or Critical Habitats	X	X	X	X	X	X	X
50 CFR 17	Endangered and Threatened Wildlife and Plants	X	X	X	X	X	X	X
50 CFR 424	Listing Endangered and Threatened Species and Designating Critical Habitat	X	X	X	X	X	X	X
33 USC § 1344 10 CFR 1022	Evaluate Federal Projects for Potential Floodplain and Wetland Impacts <sup>b/</sup>	X	X	X	X	X	X	X
Executive Order 11988	Floodplain Management - Federal Facilities	X	X	X	X	X	X	X
Executive Order 11990	Protection of Wetlands - Federal Facilities	X	X	X	X	X	X	X
10 CFR 834 (Proposed)	DOE Radiation Protection Requirements for Public Health and the Environment <sup>c/</sup>	X	X	X	X	X	X	X
DOE Order 5400.5, Chapter IV	Residual Radioactive Material in Soil	X	X	X	X	X	X	X

611

**TABLE 6.1 (Continued)**  
**POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR**  
**SOURCE AREAS FOR SURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE						
		NFA	Institutional Controls	Cap in Place	<i>In Situ</i> Stabilization/ Solidification	Excavate, Dispose	Excavate, Soil Washing	Excavate, <i>Ex Situ</i> Solidification/ Stabilization, Return
DOE Order 5820.2A, Chapter III	Low-Level Radioactive Waste Management	X	X	X	X	X	X	X
10 CFR 835 DOE Order 5480.11, Section 9	Occupational Radiation Protection Standards <sup>d/</sup>	---	X	X	X	X	X	X
29 USC §§ 657 and 667 29 CFR 1910	Worker Protection Requirements <sup>e/</sup>	---	X	X	X	X	X	X
29 USC § 668 DOE Order 5483.1A 29 CFR 1926	Occupational Health Standards for General Construction Activities <sup>f/</sup>	---	X	X	X	X	X	X
40 CFR 61, Subpart H 10 CFR 834 (Proposed)	NESHAP, Radionuclide Emissions	X	X	X	X	X	X	X
5 CCR 1001, Regulation 1	Fugitive Particulate Emissions <sup>g/</sup>	---	---	X	X	X	X	X
40 CFR 122.26 5 CCR 1002-3, 122.26	NPDES Stormwater Management Requirements	X	X	X	X	X	X	X
40 CFR 262.11 6 CCR 1007-3, 262.11	Hazardous Waste Determinations	X	X	X	X	X	X	X
DOE Order 5480.3	Packaging and Transportation Requirements for Radioactive Materials <sup>h/</sup>	---	---	---	---	X	X	---
DOE Order 5480.28	Natural Phenomena Hazard Mitigation	X	X	X	X	X	X	X

**TABLE 6.2**  
**POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR**  
**RESIDUAL SURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE						
		NFA	Institutional Controls	Vegetative Cover	Cap in Place	<i>In Situ</i> Stabilization/Solidification	Excavate, Dispose	Excavate, <i>Ex Situ</i> Soil Washing
16 USC §§ 469 and 470 36 CFR 65, 296, and 800 43 CFR 3 and 7 CRS 24-80-401 to 410	Historic and Archeological Preservation <sup>a/</sup>	X	X	X	X	X	X	X
16 USC § 661 et seq.	Fish and Wildlife Coordination Act	X	X	X	X	X	X	X
16 USC § 668	Eagle Protection Acts	X	X	X	X	X	X	X
16 USC § 701-715 50 CFR 10	Migratory Bird Treaty	X	X	X	X	X	X	X
16 USC § 1531 50 CFR 402 CRS 33-2-101 to 33-2-107	Evaluate Federal Projects for Potential Impact to Endangered or Threatened Species or Critical Habitats	X	X	X	X	X	X	X
50 CFR 17	Endangered and Threatened Wildlife and Plants	X	X	X	X	X	X	X
50 CFR 424	Listing Endangered and Threatened Species and Designating Critical Habitat	X	X	X	X	X	X	X
33 USC § 1344 10 CFR 1022	Evaluate Federal Projects for Potential Floodplain and Wetland Impacts <sup>b/</sup>	X	X	X	X	X	X	X
Executive Order 11988	Floodplain Management - Federal Facilities	X	X	X	X	X	X	X
Executive Order 11990	Protection of Wetlands - Federal Facilities	X	X	X	X	X	X	X
10 CFR 834 (Proposed)	DOE Radiation Protection Requirements for Public Health and the Environment <sup>c/</sup>	X	X	X	X	X	X	X
DOE Order 5400.5, Chapter IV	Residual Radioactive Material in Soil	X	X	X	X	X	X	X
6 CCR 1007-1, Part 4	Rules and Regulations Pertaining to Radiation Control	X	X	X	X	X	X	X
DOE Order 5820.2A, Chapter III	Low-Level Radioactive Waste Management	X	X	X	X	X	X	X

TABLE 6.2 (Continued)  
POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR  
RESIDUAL SURFACE SOIL CONTAMINATION

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE						
		NFA	Institutional Controls	Vegetative Cover	Cap in Place	<i>In Situ</i> Stabilization/ Solidification	Excavate, Dispose	Excavate, <i>Ex Situ</i> Soil Washing
10 CFR 835 DOE Order 5480.11, Section 9	Occupational Radiation Protection Standards <sup>d/</sup>	---	X	X	X	X	X	X
29 USC §§ 657 and 667 29 CFR 1910	Worker Protection Requirements <sup>d/</sup>	---	X	X	X	X	X	X
29 USC § 668 DOE Order 5483.1A 29 CFR 1926	Occupational Health Standards for General Construction Activities <sup>f/</sup>	---	X	X	X	X	X	X
40 CFR 61, Subpart H 10 CFR 834 (Proposed)	NESHAP, Radionuclide Emissions	X	X	X	X	X	X	X
5 CCR 1001, Regulation 1	Fugitive Particulate Emissions <sup>g/</sup>	---	---	X	X	X	X	X
40 CFR 122.26 5 CCR 1002-3, 122.26	NPDES Stormwater Management Requirements	X	X	X	X	X	X	X
40 CFR 262.11 6 CCR 1007-3, 262.11	Hazardous Waste Determinations	X	X	X	X	X	X	X
DOE Order 5480.3	Packaging and Transportation Requirements for Radioactive Materials <sup>h/</sup>	---	---	---	---	---	X	X
DOE Order 5480.28	Natural Phenomena Hazard Mitigation	X	X	X	X	X	X	X

**TABLE 6.3**  
**POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR**  
**RESIDUAL SUBSURFACE SOIL CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE	
		NFA	<i>In Situ</i> SVE
16 USC §§ 469 and 470 36 CFR 65, 296, and 800 43 CFR 3 and 7 CRS 24-80-401 to 410	Historic and Archeological Preservation <sup>a/</sup>	X	X
16 USC § 661 et seq.	Fish and Wildlife Coordination Act	X	X
16 USC § 668	Eagle Protection Acts	X	X
16 USC § 701-715 50 CFR 10	Migratory Bird Treaty	X	X
16 USC § 1531 50 CFR 402 CRS 33-2-101 to 33-2-107	Evaluate Federal Projects for Potential Impact to Endangered or Threatened Species or Critical Habitats	X	X
50 CFR 17	Endangered and Threatened Wildlife and Plants	X	X
50 CFR 424	Listing Endangered and Threatened Species and Designating Critical Habitat	X	X
33 USC § 1344 10 CFR 1022	Evaluate Federal Projects for Potential Floodplain and Wetland Impacts <sup>b/</sup>	X	X
Executive Order 11988	Floodplain Management - Federal Facilities	X	X
Executive Order 11990	Protection of Wetlands - Federal Facilities	X	X
10 CFR 834 (Proposed)	DOE Radiation Protection Requirements for Public Health and the Environment <sup>c/</sup>	X	X
DOE Order 5400.5, Chapter IV	Residual Radioactive Material in Soil	X	X
DOE Order 5820.2A, Chapter III	Low-Level Radioactive Waste Mngement	X	X
10 CFR 835 DOE Order 5480.11, Section 9	Occupational Radiation Protection Standards <sup>d/</sup>	---	X
29 USC §§ 657 and 667 29 CFR 1910.120	Worker Protection Requirements for Hazardous Waste/Remediation Operations <sup>e/</sup>	---	X

TABLE 6.3 (Continued)  
POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR  
RESIDUAL SUBSURFACE SOIL CONTAMINATION

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE	
		NFA	In Situ SVE
29 USC § 668 DOE Order 5483.1A 29 CFR 1926	Occupational Health Standards for General Construction Activities <sup>u</sup>	---	X
40 CFR 61, Subpart H 10 CFR 834 (Proposed)	NESHAP, Radionuclide Emissions <sup>v</sup>	X	X
40 CFR 122.26 5 CCR 1002-3, 122.26	NPDES Stormwater Management Requirements	X	X
6 CCR 1007-2, Part 2	Siting Requirements for Hazardous Waste Disposal Sites <sup>v</sup>	X	X
40 CFR 261 6 CCR 1007-3, 261	Identification and Listing of Hazardous Waste	X	X
40 CFR 262.11 6 CCR 1007-3, 262.11	Hazardous Waste Determinations	X	X
40 CFR 262, Subparts B, C, and D 6 CCR 1007-3, 262, Subparts B, C, and D	Generator Requirements for Offsite Transport of Hazardous Waste <sup>u</sup>	---	X
40 CFR 264, Subpart B 6 CCR 1007-3, 264, Subpart B	General Standards for Hazardous Waste Facilities <sup>j</sup>	---	X
40 CFR 264, Subpart C and D 6 CCR 1007-3, 264, Subpart C and D	Preparedness and Prevention and Emergency Procedures for Hazardous Waste Facilities <sup>j</sup>	---	X
40 CFR 264, Subpart E 6 CCR 1007-3, 264, Subpart E	Manifest System, Recordkeeping, and Reporting	---	X
40 CFR 264, Subpart F 6 CCR 1007-3, 264, Subpart F	Groundwater Protection and Monitoring <sup>u</sup>	---	X
40 CFR 264, Subpart G 6 CCR 1007-3, 264, Subpart G	Closure and Post-Closure	---	X

TABLE 6.3 (Continued)  
 POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR  
 RESIDUAL SUBSURFACE SOIL CONTAMINATION

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE	
		NFA	<i>In Situ</i> SVE
40 CFR 264, Subpart I 6 CCR 1007-3, 264, Subpart I	Use and Management of Containers	---	X
40 CFR 267	Identification and Listing of Hazardous Waste	X	X
42 USC § 6924 40 CFR 268, Subpart A to D 6 CCR 1007-3, 268, Subpart A to D	Land Disposal Restrictions and Treatment Standards <sup>m/</sup>	---	X
40 CFR 268, Subpart E 6 CCR 1007-3, 268, Subpart E	Prohibition on Storage of Restricted Waste	---	X
49 CFR 172, Parts B to F; 49 CFR 173, Parts B to O; 49 CFR 177	Offsite Transport of Hazardous Waste <sup>n/</sup>	---	X
DOE Order 5480.28	Natural Phenomena Hazard Mitigation	X	X

TABLE 6.4  
POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR  
UHSU GROUNDWATER

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE				
		NFA	Institutional Controls	Containment	<i>In Situ</i> Treatment	<i>Ex Situ</i> Treatment
16 USC §§ 469 and 470 36 CFR 65, 296, and 800 43 CFR 3 and 7 CRS 24-80-401 to 410	Historic and Archeological Preservation <sup>a/</sup>	X	X	X	X	X
16 USC § 661 et seq.	Fish and Wildlife Coordination Act	X	X	X	X	X
16 USC § 668	Eagle Protection Acts	X	X	X	X	X
16 USC § 701-715 50 CFR 10	Migratory Bird Treaty	X	X	X	X	X
16 USC § 1531 50 CFR 402 CRS 33-2-101 to 33-2-107	Evaluate Federal Projects for Potential Impact to Endangered or Threatened Species or Critical Habitats	X	X	X	X	X
50 CFR 17	Endangered and Threatened Wildlife and Plants	X	X	X	X	X
50 CFR 424	Listing Endangered and Threatened Species and Designating Critical Habitat	X	X	X	X	X
33 USC § 1344 10 CFR 1022	Evaluate Federal Projects for Potential Floodplain and Wetland Impacts <sup>b/</sup>	X	X	X	X	X
Executive Order 11988	Floodplain Management - Federal Facilities	X	X	X	X	X
Executive Order 11990	Protection of Wetlands - Federal Facilities	X	X	X	X	X
10 CFR 834 (Proposed)	DOE Radiation Protection Requirements for Public Health and the Environment <sup>c/</sup>	X	X	X	X	X
10 CFR 835 DOE Order 5480.11, Section 9	Occupational Radiation Protection Standards <sup>d/</sup>	---	X	X	X	X
29 USC §§ 657 and 667 29 CFR 1910.120	Worker Protection Requirements for Hazardous Waste/Remediation Operations <sup>e/</sup>	---	X	X	X	X

TABLE 6.4 (Continued)  
POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR  
UHSU GROUNDWATER CONTAMINATION

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE				
		NFA	Institutional Controls	Containment	In Situ Treatment	Ex Situ Treatment
29 USC § 668 DOE Order 5483.1A 29 CFR 1926	Occupational Health Standards for General Construction Activities <sup>u</sup>	---	X	X	X	X
40 CFR 61, Subpart H 10 CFR 834 (Proposed)	NESHAP, Radionuclide Emissions	X	X	X	X	X
5 CCR 1001 Regulation 1, III.D	Fugitive Particulate Emissions <sup>v</sup>	---	---	X	X	X
40 CFR 122.26 5 CCR 1002-3, 122.26	NPDES Stormwater Management Requirements	X	X	X	X	X
40 CFR 261 6 CCR 1007-3, 261	Identification and Listing of Hazardous Waste	X	X	X	X	X
40 CFR 262.11 6 CCR 1007-3, 262.11	Hazardous Waste Determinations	X	X	X	X	X
40 CFR 262, Subparts B, C, and D 6 CCR 1007-3, 262, Subparts B, C, and D	Generator Requirements for the Offsite Transport of Hazardous Waste <sup>w</sup>	---	---	X	X	X
40 CFR 264, Subpart F 6 CCR 1007-3, 264, Subpart F	Groundwater Protection and Monitoring <sup>x</sup>	X	X	X	X	X
40 CFR 264, Subpart G 6 CCR 1007-3, 264, Subpart G	Closure and Post-Closure Care	---	---	---	---	X
40 CFR 264/265, Subpart I 6 CCR 1007-3, 264/265, Subpart I	Use and Management of Containers	---	---	X	X	X
42 USC § 6924 40 CFR 268, Subpart A to D 6 CCR 1007-3, 268, Subpart A to D	Land Disposal Restrictions and Treatment Standards <sup>m</sup>	---	---	X	X	X
40 CFR 268, Subpart E 6 CCR 1007-3, 268, Subpart E	Prohibition on Storage of Restricted Waste	---	---	X	X	X

127

**TABLE 6.4 (Continued)**  
**POTENTIAL LOCATION- AND ACTION-SPECIFIC ARARs/TBCs FOR**  
**UHSU GROUNDWATER CONTAMINATION**

ARAR/TBC CITATION	REQUIREMENT DESCRIPTION	ALTERNATIVE				
		NFA	Institutional Controls	Containment	<i>In Situ</i> Treatment	<i>Ex Situ</i> Treatment
49 CFR 172, Parts B to F; 49 CFR 173, Parts B to O; 49 CFR 177	Offsite Transport of Hazardous Waste <sup>h/</sup>	---	---	X	X	X
DOE Order 5480.3	Packaging and Transportation Requirements for Radioactive Materials <sup>h/</sup>	---	---	X	X	X
DOE Order 5480.28	Natural Phenomena Hazard Mitigation	X	X	X	X	X

**NOTES:**

- a/ Although no historic or archeological sites are expected to be impacted, all federal actions are required to be assessed.
- b/ Although no wetlands are expected to be impacted, all federal actions are required to be assessed.
- c/ This regulation is proposed by the DOE to control radiation exposures for the protection of public health and the environment. Although NRC also has similar protection standards promulgated under 10 CFR 20.1301, the DOE regulation is identified as an ARAR for compliance purposes since the DOE regulation is consistent with the NRC standards and will be applicable to RFETS when promulgated.
- d/ Although occupational worker standards are not considered to be ARARs/TBCs, the citation to the DOE Radiation Protection Program is being provided for completeness and to ensure that these protection requirements are not overlooked when preparing the implementation plans for the selected alternative.
- e/ Although OSHA standards are not considered ARARs (see 55 FR 8680), 40 CFR 300.150 specifically requires that all response actions under the NCP maintain worker safety and health as specified under 29 CFR 1910.120. This regulation is being listed for completeness and to ensure that these protection requirements are not overlooked when preparing the implementation plans for the selected alternative.
- f/ Although OSHA standards are not considered ARARs (see 55 FR 8680), OSHA requirements would apply on their own merit. These OSHA standards apply to federal facilities as required by the Occupational Safety and Health Act [29 USC § 668] and Executive Order 12196; however, they are not independently enforced by OSHA. These occupational safety requirements are adopted and implemented under DOE Order 5483.1A. This regulation is being listed for completeness and to ensure that these protection requirements are not overlooked when preparing the implementation plans for the selected alternative.
- g/ This standard would involve the control of fugitive particulates during regrading and/or excavation activities.
- h/ Record-keeping requirements are not normally considered to be ARARs since they are procedural/administrative requirements. However, offsite response actions must comply with all applicable regulations both substantive and procedural/administrative. The generator record keeping and reporting requirements would only be applicable in the case where radioactive waste is shipped offsite.
- i/ CDPHE claims that a hazardous waste disposal site is developed in the event that hazardous waste remains in-place following the completion of closure activities. Pursuant to Part 18 of the IAG, the DOE does not have to comply with the procedural aspects of the siting regulations to obtain a Certificate of Designation for the onsite response action; however, these alternatives must comply with the substantive requirements of this regulation.
- j/ These requirements would only be applicable should a new hazardous waste storage or treatment facility be constructed as part of the alternative. These requirements would address the operation of the storage and treatment facility only. Should waste materials be stored or treated within existing onsite facilities, management of the waste will be the responsibility of the storage/treatment facility custodian.
- k/ Post-closure groundwater monitoring is required for the "dirty" closure of the landfill unless the owner/operator can demonstrate that groundwater monitoring is not necessary.

129

**Notes: (Continued)**

- l/ Interim status operational requirements apply to hazardous waste facilities until they are certified as being closed. Security, training, and inspection programs will need to be maintained and revised, if necessary, to ensure that public health and the environment are adequately protected during the closure activities.
- m/ In addition to complying with the required treatment standards for the land disposal of any designated hazardous waste offsite shipments will need to be certified as required.

## **APPENDIX A**

### **DESCRIPTION OF SOIL TECHNOLOGIES AND PROCESS OPTIONS PASSING THE TECHNICAL IMPLEMENTABILITY SCREEN**

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## APPENDIX A TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
A.1 NO FURTHER ACTION .....	A-1
A.2 INSTITUTIONAL CONTROLS .....	A-1
A.2.1 Access Restrictions .....	A-2
A.2.1.1 Fencing, Security .....	A-2
A.2.2 Land Use Restrictions .....	A-2
A.2.2.1 Deed Restrictions .....	A-3
A.2.2.2 Zoning Restrictions .....	A-3
A.2.3 Monitoring .....	A-3
A.2.3.1 Groundwater Monitoring .....	A-4
A.2.3.2 Vadose Zone Monitoring .....	A-4
A.2.3.3 Fugitive Dust Monitoring .....	A-4
A.3 CONTAINMENT .....	A-5
A.3.1 Vertical Barriers .....	A-5
A.3.1.1 Slurry Wall .....	A-5
A.3.1.2 Synthetic Membrane Cutoff Wall .....	A-6
A.3.2 Horizontal Barriers .....	A-6
A.3.2.1 Vegetative Cover .....	A-6
A.3.2.2 Asphalt-Based Cover .....	A-7
A.3.2.3 Compacted Clay Cover .....	A-7
A.3.2.4 Multi-Layer Cover .....	A-8
A.4 <i>IN SITU</i> TREATMENT .....	A-9
A.4.1 Biological Treatment .....	A-9
A.4.1.1 Enhanced Bioremediation .....	A-9
A.4.2 Chemical/Physical Treatments .....	A-11
A.4.2.1 Pneumatic Fracturing .....	A-11
A.4.2.2 Soil Gas Venting .....	A-12
A.4.2.3 Soil Vapor Extraction .....	A-12
A.4.2.4 Electrokinetics .....	A-13
A.4.2.5 Electroacoustic Soil Decontamination .....	A-13
A.4.3 Solidification/Stabilization .....	A-14
A.4.3.1 Stabilization .....	A-14
A.4.3.2 Slurry Injection .....	A-15
A.4.3.3 Solidification .....	A-15
A.4.3.4 Cementation .....	A-16
A.4.3.5 Encapsulation .....	A-16
A.4.3.6 Vitrification .....	A-16

# TABLE OF CONTENTS

(Continued)

<u>Section</u>	<u>Page</u>
A.4.4 Thermal Treatment . . . . .	A-17
A.4.4.1 Thermally Enhanced Soil Vapor Extraction . . . . .	A-18
A.5 REMOVAL . . . . .	A-18
A.5.1 Excavation . . . . .	A-19
A.5.2 Short Distance Transport . . . . .	A-20
A.5.2.1 Conveyor System . . . . .	A-20
A.5.2.2 Slurry Pipeline . . . . .	A-21
A.5.2.3 Truck Hauling . . . . .	A-21
A.5.3 Long Distance Transport . . . . .	A-22
A.5.3.1 Truck/Rail Hauling . . . . .	A-22
A.5.4 Offsite Storage/Disposal . . . . .	A-23
A.5.4.1 Landfill/TSD Facility . . . . .	A-23
A.5.5 Onsite Storage/Disposal . . . . .	A-23
A.5.5.1 Disposal Vault . . . . .	A-24
A.5.5.2 Container Storage . . . . .	A-24
A.5.5.3 Permitted Landfill . . . . .	A-24
A.6 EX SITU TREATMENT . . . . .	A-25
A.6.1 Chemical/Physical Treatment . . . . .	A-25
A.6.1.1 Chemical Reduction/Oxidation (Red/Ox) . . . . .	A-26
A.6.1.2 Soil Washing . . . . .	A-26
A.6.1.3 Solvent Extraction . . . . .	A-27
A.6.1.4 Electrokinetics . . . . .	A-28
A.6.1.5 Physical Separation . . . . .	A-28
A.6.1.6 Magnetic Separation . . . . .	A-28
A.6.1.7 Dehalogenation . . . . .	A-28
A.6.1.8 Soil Vapor Extraction . . . . .	A-30
A.6.2 Biological . . . . .	A-30
A.6.2.1 Biological Leaching . . . . .	A-31
A.6.3 Solidification/Stabilization . . . . .	A-31
A.6.3.1 Stabilization . . . . .	A-32
A.6.3.2 Encapsulation . . . . .	A-32
A.6.3.3 Cementation . . . . .	A-32
A.6.3.4 Vitrification . . . . .	A-33
A.6.4 Thermal Treatments . . . . .	A-34
A.6.4.1 Incineration . . . . .	A-34
A.6.4.2 Low-Temperature Thermal Desorption . . . . .	A-38

**TABLE OF CONTENTS**  
(Continued)

<u>Section</u>	<u>Page</u>
A.6.4.3 HT-5 Thermal Distillation Process . . . . .	A-39
A.6.4.4 Pyrolysis . . . . .	A-40

## DESCRIPTION OF SOIL TECHNOLOGIES AND PROCESS OPTIONS PASSING THE TECHNICAL IMPLEMENTABILITY SCREEN

This appendix provides a description of the technologies and process options that have passed the technical implementability screen, and are being considered for remediation of contaminated soil at RFETS. The technologies included in this appendix cover the range of options and approaches available to treat contaminated soil or otherwise protect human health and the environment. These technologies alone or in combination have been considered in the development of alternatives to satisfy the remedial action objectives. EPA guidance documents, engineering reference materials, technical journals, periodicals, and reference data bases were used to prepare these technology descriptions.

The technologies are organized in general by general response action, technology type, and process option. The following general response actions are no action, institutional actions, containment, removal, transport, storage and disposal, *in situ* treatment, and *ex situ* treatment.

### A.1 NO FURTHER ACTION

The no action option provides a baseline exposure risk scenario for comparison with the risks associated with implementation of other technology types. No action means no response to potential soil contamination and no interruption of potential human health and environmental exposure pathways. Although nothing is implemented to address soil contamination under no action, natural processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions may occur. These processes are collectively referred to as natural attenuation, and over time may reduce contaminant concentrations. Contaminants that may be degraded, removed, or reduced as a result of natural attenuation include non-halogenated volatile and semivolatile organics and petroleum hydrocarbons. Other compounds such as halogenated volatiles and semivolatiles, pesticides, and inorganics may also naturally attenuate, but not as effectively.

The following factors may limit the applicability and effectiveness of the process:

- No action and natural attenuation should be used only in low-risk situations; and
- No action may require periodic soil, surface water, and groundwater monitoring (EPA, 1988) to determine if any changes have taken place in short-term and long-term risks.

### A.2 INSTITUTIONAL CONTROLS

Institutional controls reduce exposure to site contaminants through administrative actions and access restrictions. Administrative actions include land access and use restrictions and monitoring of conditions at the site. The intent of access restrictions is to interrupt exposure pathways. Access restrictions include barriers, fencing, and warning signs.

Institutional controls may be appropriate for sites where the potential for exposure is minimal, or where baseline risks are determined to be low. However, institutional controls may also be selected for highly contaminated sites where the risks to workers or community during remediation would exceed the present risks at the site. In this case, institutional controls could include site access restrictions.

As indicated above, institutional controls may be combined with other response actions to satisfy remedial action objectives. For example, if a site is remediated through containment or treatment, institutional controls such as deed restrictions or access restrictions may be implemented during, as well as after, the site is remediated.

#### **A.2.1 Access Restrictions**

Access restrictions reduce potential exposures by limiting access to contaminated areas. Such restrictions include warning signs, fences, and other physical barriers, and can also include security systems such as guards, lighting, and alarms. The most common access restriction applicable to humans is fencing.

The following factors may limit the applicability and effectiveness of the process:

- Access restrictions may have to be expanded if contaminants migrate; and
- It is difficult to establish vertical access restrictions.

##### **A.2.1.1 Fencing, Security**

Exposure to contaminants would be reduced or eliminated by installing a fence around the entire site. Long-term security would be provided to ensure that the public does not enter into the restricted area. Monitoring would be needed to ensure that the contaminants are not migrating outside the fenced area. If contamination migration occurred, the fenced area may need to be expanded to ensure protection of the public.

#### **A.2.2 Land Use Restrictions**

Exposure to contaminants may be reduced or eliminated through land use restrictions. Land use restrictions may be incorporated in deeds or zoning requirements. Often deed and zoning restrictions must be considered together because deed restrictions indicate what cannot be done, and zoning restrictions indicate what can be done. Before deed restrictions can be implemented, a comprehensive title search would be needed to verify "Fee Simple" ownership (i.e., mineral, water, and other inherent rights) of the land.

#### **A.2.2.1 Deed Restrictions**

Exposure to contaminants may be reduced or eliminated by adding restrictions to the property deed that limit the future land use. For example, residential or commercial construction in contaminated areas could be prohibited by defining those areas and adding an appropriate stipulation in the property deed. The contaminants would not be removed, but may be reduced over time by natural attenuation.

The following factors may limit the applicability and effectiveness of the process:

- The mineral, water, or other inherent rights must be purchased if they are owned by another party; and
- Potential present and future legal challenges may cause difficulties.

#### **A.2.2.2 Zoning Restrictions**

Exposure to contaminants may be reduced or eliminated by restricting future land use through zoning ordinances. Zoning restrictions would restrict development or use of the entire property rather than just the contaminated areas. Again, the contaminants would not be removed, but may be reduced over time by natural attenuation.

The following factors may limit the applicability and effectiveness of the process:

- Zoning restrictions may be changed, by public and institutional decree, at any time; and
- Potential present and future legal challenges may cause difficulties.

#### **A.2.3 Monitoring**

Monitoring of surface water, groundwater, vadose zone moisture, or fugitive dust may be incorporated into a remedial action alternative to evaluate site conditions before, during, and after remediation. Monitoring involves periodic sampling and analysis to determine if surface water, groundwater, vadose zone, or fugitive dust contaminants have degraded or migrated. Monitoring does not reduce contaminant toxicity, mobility, or volume. Consultants and laboratories that conduct surface water, groundwater, vadose zone, and fugitive dust monitoring are readily available.

The following factors may limit the applicability and effectiveness of the process:

- Stratification of contaminants in stagnant waters must be considered; and

- Proper location and installation of the monitoring wells can be difficult, and should be based on all available contaminant data as well as on geologic and hydrogeologic data.

#### **A.2.3.1 Groundwater Monitoring**

Site-specific characteristics that influence the placement of monitoring wells include the nature of the aquifer (e.g., artesian); characteristics of potential leachate; and groundwater depth, flow rates, and direction of flow. Based on assumptions and data about the characteristics of the site, approximate permeability of soils in the zone of aeration, and directions and velocities of groundwater flow, the maximum probable areal extent of contaminant migration can be estimated as a basis for establishing the position of monitoring wells.

Proper location and installation of monitoring wells are essential to a monitoring program. A minimum of four groundwater monitoring wells are typically installed at a hazardous waste site: one upgradient well and three downgradient wells. However, site hydrogeology is often too complex for only four wells to provide adequate detection of groundwater contamination.

Upgradient wells are placed beyond the upgradient extent of contamination. At least three downgradient wells are located to ensure that releases of hazardous waste or hazardous-waste constituents from the hazardous waste management unit(s) to the uppermost aquifer will be quickly detected. The specific number of wells to be included in a detection system depends on the horizontal spacing between well locations and the vertical sampling interval of individual wells.

#### **A.2.3.2 Vadose Zone Monitoring**

Monitoring of the vadose zone (i.e. the unsaturated zone) of soil beneath a hazardous waste site is currently not required by federal regulations. However, vadose zone monitoring can be used to demonstrate that overlying contaminants have not migrated into the vadose zone and also that existing contaminants in the vadose zone are not moving.

The most commonly used monitoring tool in the vadose zone is the suction lysimeter. Suction lysimeters are installed in the vadose zone beneath the hazardous waste site and beneath any low-permeability liners. Backup lysimeters are often installed beneath or adjacent to the primary lysimeter to verify results.

#### **A.2.3.3 Fugitive Dust Monitoring**

Monitoring of fugitive dust primarily includes radiological surveys. These surveys can be used to demonstrate that contaminated soils are not migrating via the wind/air dispersion pathway. Ambient air samplers monitor airborne dispersion of radioactive materials. Samplers

operate continuously at a volumetric flow rate of approximately 12 liters per second, collecting air particles on fiberglass filters.

### **A.3 CONTAINMENT**

Containment interrupts the exposure pathways to contaminated soil, and prevents or reduces migration of hazardous substances into the surrounding environment. While containment reduces the mobility of the contaminants, it does not reduce their toxicity or volume. Containment technologies include horizontal and vertical barriers.

#### **A.3.1 Vertical Barriers**

Vertical barriers prevent horizontal migration of contamination by introducing or creating a physical barrier around all or part of the contaminated soil mass. Slurry walls and synthetic membrane cutoff walls are types of vertical barriers.

##### **A.3.1.1 Slurry Wall**

These subsurface barriers consist of a vertically excavated trench filled with a slurry. The slurry, usually a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and forms a filter cake to reduce groundwater flow. In some cases, soil or cement is added to the bentonite slurry to form a soil-bentonite or cement-bentonite barrier. Slurry walls can be "keyed" to a confining layer of clay or bedrock, or left "hanging" when contaminants such as petroleum hydrocarbons do not mix with the groundwater. Slurry walls are often used where the waste mass is too large for practical treatment and where soluble and mobile constituents pose an imminent threat to a drinking water source. They are economical at moderate depths (40 to 70 feet), and have a low water permeability (from  $10^{-5}$  to  $10^{-8}$  cm/sec). Slurry walls have been successfully implemented at hazardous waste sites, are applicable to the full range of contaminants with no particular target group, but are considered capital-intensive.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants to a specific area;
- Soil-bentonite backfills are not able to withstand attack by strong acids, bases, salt solutions, and some organic chemicals. There is some concern regarding the permeability of slurry walls to certain organic compounds;
- There is the potential for the slurry walls to degrade or deteriorate over time; and
- The trenches are generally limited to an excavated depth of approximately 30 feet using conventional backhoes. Greater depths, approaching 70 feet, can be achieved using telescopic backhoes or clamshells.

### **A.3.1.2 Synthetic Membrane Cutoff Wall**

Synthetic membranes are used to form a cutoff wall to divert or contain groundwater. Compatibility testing of the liners with chemical wastes must be performed to determine durability. To place a synthetic membrane liner as a vertical barrier, a trench must be dug from the surface to an impervious soil layer, and a drain must be placed in the bottom of the trench to remove excess water. The synthetic membrane must be suspended vertically in the trench, and the trench must be backfilled with sand or other suitable material. To be effective, the liner must be keyed into the underlying impervious barrier. During construction, the trench must remain open to facilitate placement of the liner. Extra precautions must be taken when working with loose, unconsolidated materials to ensure proper placement of the liner.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants to a specific area;
- Construction, depending on site conditions, may be difficult and the synthetic membrane may become damaged; and
- The trenches are generally limited to an excavated depth of approximately 30 feet using conventional backhoes. Greater depths, approaching 70 feet, can be achieved using telescopic backhoes or clamshells.

### **A.3.2 Horizontal Barriers**

Horizontal barriers reduce contaminant migration from soils and sediments by minimizing contaminant entrainment as dust, leaching, infiltration, and/or contact with surface water runoff. Horizontal barriers are effective in containing organic and inorganic contaminated soils.

Exposure pathways to contaminants in soils and sediments are also interrupted by horizontal barriers. Horizontal barriers include caps and covers, grout injection pavement, and sprayed sealants.

#### **A.3.2.1 Vegetative Cover**

Vegetative cover processes include grading and backfilling the contaminated area with general backfill/topsoil material, planting vegetation, and applying pea gravel.

The following factors may limit the applicability and effectiveness of the process:

- Backfilling and grading provide no hydraulic barriers to prevent infiltration of precipitation into underlying material;
- Soil types and availability of water are critical for development of a vegetative surface;
- Periodic repair and maintenance may be required;
- The process is not usually considered a long-term containment process; and
- Monitoring and a leak detection system may be required.

#### **A.3.2.2 Asphalt-Based Cover**

An asphalt-based cover involves placing an asphalt layer over a crushed-stone bedding layer directly on the site surface. Before the pavement is placed, the site surface must be compacted and graded to prevent differential settlement. Pavement is subject to cracking through weathering processes, and has not frequently been used for long-term containment of hazardous wastes.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants in a specific area;
- Pavement is susceptible to damage by weather (e.g., sun and the freeze/thaw cycle), plants, and animals;
- Design life may be inappropriate for the contaminants of concern;
- Periodic repair and maintenance may be required;
- The process is not usually considered a long-term containment process; and
- Monitoring and a leak detection system may be required.

#### **A.3.2.3 Compacted Clay Cover**

Compacted clay is frequently used in single or multiple layers in the final cover system of both hazardous and municipal waste landfills. These cover systems may also be used to contain contaminated soils. Bentonite, a natural clay with high swelling properties, is often transported to a site and mixed with onsite soil to produce a low-permeability cover material. Onsite soils can sometimes be compacted to achieve the required permeability of  $1 \times 10^{-7}$  cm/sec

or less. Vegetation is typically the final surface of a cover system. Proper vegetation reduces the damaging effects from erosion due to wind and surface water runoff.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants in a specific area;
- The uniformity of compacted soil walls is difficult to control;
- The cover may require large volumes of construction material;
- Weathering (cracking) of the clay cover may require extensive maintenance; and
- Monitoring and a leak detection system may be required.

#### **A.3.2.4 Multi-Layer Cover**

Clay, compacted soil, or synthetic membranes are frequently used in single or multiple layers in the final cover system of both hazardous and municipal waste landfills. These cover systems may also be used to contain contaminated soils. Bentonite, a natural clay with high swelling properties, is often transported to a site and mixed with onsite soil to produce a low-permeability cover material. Onsite soils can be compacted to achieve the required permeability of  $1 \times 10^{-7}$  cm/sec or less. The most common synthetic membrane materials are polyvinyl chloride, polyethylene, butyl rubber, Hypalon®, and neoprene.

An example of a multi-layer cover consists of the following: (1) a gas-collection layer, (2) a composite hydraulic barrier layer combining a compacted-clay and a flexible-membrane liner, (3) a biotic barrier and drainage layer, (4) a topsoil layer, and (5) a permanent vegetative cover.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants in a specific area;
- The uniformity of compacted soil walls is difficult to control;
- Synthetic membrane materials can be easily damaged by weather, human activity, and animals;
- Synthetic membrane materials can degrade over time and may need to be maintained or replaced; and
- Monitoring and a leak detection system may be required.

## **A.4           IN SITU TREATMENT**

*In situ* treatment of contaminated soils and sediments is conducted without removal of contaminated material. *In situ* treatment technologies are generally not as well developed or tested as direct treatment equivalents and are highly dependent on site conditions. *In situ* technologies may also involve the delivery of solutions or reagents to the zone of contamination, as well as the control of the spread of contaminants and treatment reagents beyond the subsurface treatment zone. Applicability of *in situ* methods must generally be established on a site-specific basis by pilot-scale treatability studies. *In situ* treatments include biological, chemical/physical, and thermal treatments.

### **A.4.1           Biological Treatment**

Bioremediation uses naturally occurring micro-organisms, such as bacteria, fungi, or yeast, to degrade harmful chemicals into less toxic or nontoxic compounds. Micro-organisms, like all living organisms, need nutrients (such as nitrogen, phosphate, and trace metals), carbon, and energy to survive. Micro-organisms break down a wide variety of organic (carbon-containing) compounds found in nature to obtain energy for their growth. Many species of soil bacteria, for example, use petroleum hydrocarbons as a food and energy, transforming them into harmless substances consisting mainly of carbon dioxide, water, and fatty acids. Bioremediation harnesses this natural process by promoting the growth of micro-organisms that can degrade contaminants and convert them to less toxic or nontoxic byproducts. The major *in situ* biological treatment technologies include biodegradation, bioventing, bio-uptake, and land farming/agricultural practices.

#### **A.4.1.1       Enhanced Bioremediation**

The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance *in situ* biological degradation of organic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. Generally, the process includes above-ground treatment and conditioning of the infiltration water with nutrients and an oxygen (or other electron acceptor) source. Bioremediation has been successfully applied at hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

- Extensive treatability studies and site characterization may be necessary;
- The circulation of water-based solutions through the soil may increase contaminant mobility and necessitate use of an aboveground system for treating water prior to re-injection or disposal;

- The injection of micro-organisms into the subsurface is not recommended, and naturally occurring organisms are generally adapted to the contaminants present;
- Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones;
- The system should be used only where groundwater is near the surface and where the groundwater underlying the contaminated soils is contaminated;
- The system should not be used for clay, highly layered, or heterogeneous subsurface environments due to oxygen (or other electron acceptor) transfer limitations; and
- Bioremediation may not be applicable at sites where there are high concentrations of heavy metals, highly chlorinated organics, or inorganic salts.

Target contaminants for *in situ* bioremediation are non-halogenated volatile and semivolatile organics and petroleum hydrocarbons. Halogenated volatile and semivolatile organics and pesticides also can be treated, but the process may be less effective and may only be applicable to some of these compounds.

The overall cost of *in situ* bioremediation should be in the range of \$100-\$300/ton.

*In situ* bioremediation is considered operations and maintenance (O&M)-intensive. Various quantities of nutrients or other amendments must be obtained and circulated through contaminated soils, and their concentrations and effects on contaminant degradation rates must be monitored.

*In situ* bioremediation has been demonstrated to treat low levels of organic contaminants and is especially attractive at sites where soil excavation is difficult or expensive or where soil remediation can be tied into groundwater treatment. The most common type of *in situ* bioremediation treatment involves aerobic degradation of contaminants adsorbed onto soils within the saturated zone of a site. The process involves the addition of small amounts of nutrients (ammonia and phosphate) and large quantities of an oxygen source (e.g., hydrogen peroxide). This is accomplished by injecting nutrient-enriched solutions into the contaminated zone through a series of wells or trenches and recovering the downgradient groundwater.

For the process to be effective, the injection/recovery system must provide for the transport of nutrients throughout the entire contaminated zone. If possible, this should follow the contaminant pathway. This is particularly difficult in the vadose zone or at sites with complex underlying geology or low permeability soils. Methane-oxidizing processes may be effective in enhancing degradation of volatile halogenated compounds.

Anaerobic bioremediation has not been demonstrated for *in situ* applications because of the difficulty in maintaining an oxygen-free environment and because of the temperature sensitivity of the microbes. Research is currently being conducted to investigate the feasibility of anaerobic bioremediation for deep soils or aquifers.

#### A.4.2 Chemical/Physical Treatments

Physical treatment is a process in which the hazardous waste is separated from its carrier by various physical methods including adsorption, distillation, and filtration. Physical treatment is applicable to a wide variety of wastes, but further treatment is usually required. For this reason, physical treatment is often discussed along with chemical treatment.

Chemical treatment is a process in which the hazardous waste is altered by a chemical reaction to destroy the hazardous component. Wastes that can be treated by this method include both organic and inorganic compounds. Drawbacks to this method include the inhibition of the treatment process reaction by impurities in the waste and the potential generation of hazardous byproducts.

The major *in situ* physical/chemical technologies include: pneumatic fracturing, soil flushing, hydrolysis, chemical oxidation, and soil vapor extraction.

##### A.4.2.1 Pneumatic Fracturing

Pneumatic fracturing is normally combined with other *in situ* processes such as soil flushing or vapor extraction to improve contaminant removal. Pressurized air is injected beneath the surface to develop cracks in low permeability and over-consolidated sediments. These new passageways increase the effectiveness of many *in situ* processes and enhance extraction efficiencies.

The following factors may limit the applicability and effectiveness of the process:

- The technology should not be used in areas of high seismic activity;
- Investigation of possible underground utilities, structures, or trapped free product is required; and
- The potential exists to open new pathways for the unwanted migration of contaminants (e.g., dense non-aqueous phase liquids).

Pneumatic fracturing is applicable to the complete range of contaminant groups with no particular target group. The technology is used primarily to fracture clays and bedrock, but has applications in aerating sandy formations. Normal operation employs a two-person crew, who make 25 to 40 fractures per day with a fracture radius of 15 to 20 feet (4.6-6.1 meters) to a depth of 50-100 feet (15.2-30.5 meters).

The normal cost range for pneumatic fracturing is \$5-\$10/ton (\$5.50-\$11.00/metric ton). Pneumatic fracturing is not considered capital- or O&M-intensive.

#### A.4.2.2 Soil Gas Venting

If organic hazardous or nonhazardous waste is deposited in a pit, trench, or landfill, landfill gas (LFG) production can be expected. Landfill gas is produced by anaerobic decomposition of organic material, and consists primarily of methane and carbon dioxide, but could also contain small concentrations of other volatile organic gases such as vinyl chloride. LFG can be flammable and sometimes explosive. Landfill gas can move vertically and laterally through soils under a pressure gradient or a concentration gradient via diffusion.

Landfill gas from hazardous-waste sites is currently either vented into the atmosphere or collected and flared or incinerated. Atmospheric vent systems usually consist of a series of horizontal, perforated collection pipes located on top of the landfilled material and under the final cover; the LFG is vented to the atmosphere via vertical riser pipes. Alternatively, the LFG can be collected via an extraction blower and flared or incinerated if it is too toxic or odoriferous for direct ventilation.

#### A.4.2.3 Soil Vapor Extraction

Soil vapor extraction (SVE) applies a vacuum through extraction wells to create a pressure gradient that induces volatile compounds to diffuse through the soil to extraction wells. The basic components of an *in situ* vacuum extraction system include production wells, monitoring wells, and high-vacuum pumps. The vacuum pumps are connected via a piping system to a series of production wells drilled through the contaminated soil zone. Spacing of the production wells is determined by mathematical models or pilot testing. Monitoring wells are drilled around the production wells to monitor the interstitial air pressure. Placing air injection wells between the production wells, or placing an impermeable cover over the surface of the zone being treated may improve air flow through the soil. These approaches prevent the air in the vicinity of the production wells from "short-circuiting" by constraining the air to flow laterally through the soil. The process includes a system for handling off-gases. The system for handling the off-gases usually includes a liquid/vapor separator and is treated by an activated carbon bed, catalytic converter, or afterburner. This process also is known as *in situ* soil venting, *in situ* volatilization, enhanced volatilization, and soil vacuum extraction.

The following factors may limit the applicability and effectiveness of the process:

- High humic content of soil inhibits contaminant volatilization;
- Heterogeneous soil conditions may result in inconsistent removal rates; and
- Low soil permeability limits subsurface air flow rates and reduces process efficiency.

Halogenated and non-halogenated volatile organic compounds and petroleum hydrocarbons are the target contaminant groups for *in situ* SVE (Stinson, 1989). The technology is applicable only to volatile compounds with a Henry's Law constant greater than 0.01 or a vapor pressure greater than 0.5 units. *In situ* SVE generally applies only to the vadose zone. Treatment of the saturated zone is only possible by artificially lowering the water table. Since SVE is an *in situ* remedy and all contaminants are under vacuum until treatment, the possibility of contaminant release is reduced.

Data indicate that the overall cost for *in situ* SVE is typically under \$50/ton, excluding treatment of off-gases and collected groundwater. SVE is considered O&M intensive.

*In situ* SVE may be enhanced by the injection of heat using thermal technologies. Since higher temperatures cause enhanced volatilization and the configuration of the systems requires a thermal component, details of thermally enhanced SVE are presented in Section A.4.4.3 under Thermal Treatments.

#### A.4.2.4 Electrokinetics

Electrokinetic soil processing is an *in situ*, continuous process for the removal of ionic or charged species from soils including: heavy metals, radionuclides, and selected organic pollutants. Electrokinetics is the process of passing a low-intensity direct current through contaminated soil. The double-layer theory plays an important role when electric potential is applied to the soils. For soil particles, the double layer consists of a fixed layer of negative ions that are firmly held to the solid phase and a diffuse layer of cations and anions that are more loosely held. Applying an electric potential to soil promotes migration of the loosely held ions to their respective electrodes, dragging water molecules along with them as they move toward the electrodes. The electric field is expected to increase the leaching rate of heavy metals, which can be precipitated from solution by establishing appropriate pH and osmotic gradients. To date, electrokinetics has not been demonstrated beyond the bench scale for remediation of contaminated soil. The energy requirements are quite high during implementation of the process.

#### A.4.2.5 Electroacoustic Soil Decontamination

*In situ* electroacoustic soil decontamination is an emerging technology used for decontamination of soils containing hazardous organics by applying electrical (direct current) and acoustic field. The direct current facilitates the transport of liquids through soils. The process consists of electrodes (an anode and a cathode) and an acoustic source. Applying an electric potential displaces ions loosely held on soil particles, and the cations drag water along with them as they move toward the cathode. Although the phenomenon is not fully understood, an acoustic field can enhance the dewatering or leaching of wastes such as sludges when properly applied in conjunction with an electric field and water flow. One other possible application of the acoustic field is unclogging recovery wells. The technology is most applicable for fine-grained clay soils. Early results indicate that electroacoustic soil decontamination is technically feasible

for removal of inorganic species, such as zinc and cadmium, from clay soils, and only marginally effective for hydrocarbon removal (SITE Technology Profile, undated).

#### **A.4.3 Solidification/Stabilization**

Contaminants are physically bound or enclosed within a stabilized mass (solidification), and/or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility.

The following factors may limit the applicability and effectiveness of the process:

- Depth of contaminants;
- Environmental conditions which affect the ability to maintain immobilization of contaminants;
- A significant increase in volume (up to double the original volume) with some processes; and
- Incompatibility of certain wastes with this process; treatability studies may be required.

The target contaminant group for *in situ* solidification/stabilization is inorganics. The technology's effectiveness against halogenated and non-halogenated semivolatile organic compounds and pesticides is currently limited; however, systems designed to be more effective in treating organics are being developed and tested. *In situ* solidification/stabilization is relatively simple, uses readily available equipment, and has high throughput rates compared to other technologies.

Overall cost of *in situ* solidification/stabilization should be less than \$100/ton. *In situ* solidification/stabilization is considered to be capital-intensive.

*In situ* solidification/stabilization technologies include: pozzolanic-based solidification, cement-based solidification, and proprietary agent solidification.

##### **A.4.3.1 Stabilization**

Stabilization refers to a process by which a waste is converted to a more chemically stable form. The term may include solidification and the use of a chemical reaction to transform the toxic component to a new, nontoxic compound or substance. Biological processes, however, are not considered. Stabilization or solidification is often accomplished using proprietary agents to react with or bind wastes under *ex situ* conditions.

Most proprietary processes are protected from unauthorized use by patent or copyright laws. Several proprietary agent processes are very similar and, therefore, extensive bench-scale testing is advisable. Acceptable results from testing of more than one process can achieve cost savings through competitive pricing.

Stabilization uses a variety of chemical agents to react with soil contaminants to produce a less mobile or less toxic compound. A number of proprietary solidification agents have been used for *in situ* solidification/stabilization at hazardous waste sites. This process is similar to pozzolanic-based solidification/stabilization, using conventional earth-moving equipment or modified drilling techniques for mixing. Several proprietary agent binders are available to assist in binding organics; however, the process works best for inorganics and metals. Some agents used in this process may cause a significant volume increase in treated soil.

#### **A.4.3.2 Slurry Injection**

Slurry injection includes the injection of a slurry mixture containing chemical reagents into the soil, where it hardens and immobilizes any contaminants. Slurry injection is an innovative technology and its long-term effectiveness is unknown.

The following factors may limit the applicability and effectiveness of the process:

- Contaminants immobilized, but not removed;
- Freeze/thaw degradation;
- Rocks larger than 10 inches;
- Soil volume increases of up to 8.5 percent; and
- Access would be required for a drill rig and mixing equipment.

#### **A.4.3.3 Solidification**

Soil mixing techniques and pozzolonic agents are used to produce a solidified soil mass. The required equipment and materials are readily available and the process is considered to be a proven, established, full-scale technology.

The following factors may limit the applicability and effectiveness of the process:

- Reduces mobility and results in an increase in soil volume;
- High organic concentrations may impede setting and binding;
- Heterogeneous and high moisture soil may be more difficult to treat;

- Pilot testing may be needed to specify design requirements; and
- Maintenance of the solidified mass, monitoring, and periodic sampling may be required.

#### A.4.3.4 Cementation

Cement-based and pozzolanic-based solidification/stabilization has been used for *in situ* applications at several hazardous waste sites. This technology requires a method to mix the solidification/stabilization cementitious agents with the soil in place. Conventional earth-moving equipment can be used for mixing at shallow depths, but greater depths require a more sophisticated mixing method such as that presented for slurry injection solidification.

#### A.4.3.5 Encapsulation

Encapsulation is a process involving the complete coating or enclosure of waste particles individually (microencapsulation) or as an agglomerated mass (macroencapsulation). The process is typically performed on excavated and/or already treated or drummed wastes. However, this process may be applied under *in situ* conditions using existing injection grouting technology or existing soil mixing technology for shallow soils. No reference to the successful use of the *in situ* process was found in the literature; however, it has been cited as having significant applicability and promise by Freeman (1989).

#### A.4.3.6 Vitrification

*In situ* vitrification is the process of decomposing organic contaminants and melting wastes, soils, or sludges in place to bind the waste into a glassy, solid matrix that is very resistant to leaching. This is accomplished by electrically melting soil at temperatures between 2900 and 3600 degrees Fahrenheit. Organic vapors and airborne particulates from the organic contaminants and some inorganic contaminants are collected at the surface under a hood and drawn into an off-gas treatment system. Electricity is typically supplied by a utility distribution system transmitting 12,500 or 13,800 volts. The resulting product is a monolithic mass with a microcrystalline structure similar to that of naturally occurring obsidian. Vitrification is currently in pilot-scale development with some applications at hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

- The process requires homogeneity of the media;
- *In situ* vitrification is only effective to a maximum depth of approximately 30 feet;
- Organic and inorganic off-gases must be controlled;

- *In situ* vitrification is limited to operations in the vadose zone;
- Soil moisture may increase the process costs;
- Buried metals in excess of 5 percent of the melt weight, or continuous metal that occupies 90 percent of the distance between two electrodes, will hinder performance; and
- There may be insufficient silica in the treatment volume to form the desired residual material.

While *in situ* vitrification is used primarily to encapsulate non-volatile inorganic elements, temperatures of approximately 3000°F (1600°C) destroy organic contaminants by pyrolysis. *In situ* vitrification will result in a volume reduction of 20-40 percent, depending on the material void volume. A vacuum hood placed over the treated area collects off-gases, which are treated before release. The entire process may be conducted in a vacuum, greatly reducing the possibility of contaminant release. Controlling the off-gases and the high voltage used in the *in situ* vitrification process presents some health and safety risks.

The cost of *in situ* vitrification has been estimated to be approximately \$790/ton (\$870/metric ton). *In situ* vitrification is a relatively complex technology requiring highly skilled and trained operators. It is considered to be both capital- and O&M-intensive.

#### A.4.4 Thermal Treatment

Thermal treatment involves the application of thermal energy to contaminated soils or hazardous waste by various means. Thermal energy can be used to combust or burn contaminants, volatilize contaminants, or trap contaminants within a vitrified mass. Depending on the application, temperatures of the treated material can be raised slightly or dramatically. When subjected to elevated temperatures, organic wastes can decompose to less toxic forms, or can volatilize and be captured. Complete combustion yields carbon dioxide and water plus small amounts of carbon monoxide, nitrous oxides, and chlorine and bromine acid gases. Some thermal processes produce off-gases and ash that require further treatment or landfill disposal. Thermal treatment is most suitable for organic wastes and is less effective when attempting to detoxify heavy metals and inorganic compounds. Thermal treatments may be applied to enhance chemical/physical treatments such as SVE. One drawback of thermal treatment is the high cost involved.

#### **A.4.4.3 Thermally Enhanced Soil Vapor Extraction**

Thermally enhanced SVE uses steam/hot-air injection or electric/radio frequency heating to increase the mobility of volatiles to facilitate extraction. The process includes a system for handling off-gases. Thermally enhanced SVE has been applied to contaminated soils at hazardous waste sites and is designed to treat halogenated and non-halogenated semivolatile organic compounds. Thermally enhanced SVE technologies are also effective in treating some pesticides, depending on the temperatures achieved by the system. The technology may also be used to treat some halogenated and non-halogenated volatile organic compounds and petroleum hydrocarbons, but effectiveness may be limited.

The following factors may limit the applicability and effectiveness of the process:

- Debris or other large objects buried in the media can cause operating difficulties;
- Use of the technology is limited to a slope of 5° or less;
- Performance varies depending upon the process selected because of the maximum temperature achieved; and
- The soil structure at the site may be modified depending upon the process selected.

The thermally enhanced SVE processes used by each vendor are notably different and should be investigated individually for more detailed information. Heating mechanisms employed by vendors may include, but are not limited to, radio frequency heating (Section A.4.4.2) and 6-phase heating. A 6-phase heating demonstration project is underway at RFETS; results will be available under separate cover. Since thermally enhanced SVE is an *in situ* remedy and all contaminants are under a vacuum during operation, the possibility of contaminant release is minimal.

Available data indicate that the overall cost for treatment using thermally enhanced SVE systems is approximately \$50-\$75/ton (\$55-\$82/metric ton), excluding treatment of off-gases and groundwater. Thermally enhanced SVE is considered to be both capital- and O&M-intensive.

#### **A.5 REMOVAL**

Contaminated material may be removed and transported to treatment and/or disposal facilities. Excavation is one type of removal technology and is applicable to all the contaminants. Removal actions are performed on contaminated soils so they can be treated aboveground or disposed of. Long-term exposure pathways associated with the contaminated soils are therefore minimized or eliminated. Excavation may create short-term risks associated with fugitive dust, direct exposure to contaminated soils, and physical hazards related to excavation equipment.

157

The following factors may limit the applicability and effectiveness of the removal technologies:

- Generation of fugitive emissions may be a problem during removal operations;
- The distance between the contaminated site and the nearest treatment/disposal facility may be too great;
- Community acceptability may be difficult;
- Depth and composition of the media requiring excavation must be considered;
- Applicable Land Disposal Restrictions must be considered;
- Quantity of contaminated soil may be impractical;
- Characteristics of contaminated soil may be limiting; and
- Site-specific conditions (i.e., topography, location, geology) may be limiting.

#### **A.5.1 Excavation**

Excavation includes all excavation techniques used in removing wastes or contaminated material. Conventional techniques and equipment are used for most hazardous waste remediation with modifications to procedures or equipment to ensure the health and safety of equipment operators, the public, and the environment. When removal of wastes requires drastic modification to conventional equipment or procedures, techniques are used. These processes include robotic technologies, excavation within emission control enclosures, excavation using foam suppressants, and other techniques to handle special situations posed by highly toxic, corrosive, explosive, or sensitive wastes.

The following factors may limit the applicability and effectiveness of the process:

- Groundwater table elevation may cause problems with excavation;
- The costs associated with excavating sites containing radioactive, reactive, or highly toxic waste material may be prohibitive;
- The generation of fugitive emissions may be a problem during operations;
- Requirements for sensing/monitoring equipment at the dig face may be problematic;

- The potential exists to open new pathways for the unwanted migration of contaminants; and
- Excavation may become cost-prohibitive at great depths or in complex hydrogeologic conditions.

## **A.5.2 Short Distance Transport**

Transportation is the physical removal of soil from a site after excavation. Transport actions do not treat contaminants but provide a means of moving contaminated materials to onsite or offsite treatment facilities. Short distance transport includes processes that move contaminated material relatively short distances. For example, short distance transport may include transport of contaminated material from the site of removal to a treatment facility located onsite, or from a staging or stockpiling area to a treatment facility. Short distance transport methods include conveyor systems, slurry pipelines, and truck hauling methods. Soils may be placed in drums or rolloff containers prior to transportation. The selection of a specific transport process must consider the distance and purpose of transport.

### **A.5.2.1 Conveyor System**

Conveyor systems can be used to transport contaminated materials as part of a treatment alternative or processing system. They require removal, loading system, and potentially additional transport methods to move contaminated materials from one location to another. Conveyor systems are readily available under numerous designs to meet various process design requirements. Conveyor systems are typically used to transport materials over relatively short distances as temporary or long-term systems.

The following factors may limit the applicability and effectiveness of the process:

- The distance between the contaminated site and the nearest treatment/disposal facility;
- Quantity of the contaminated material;
- Characteristics of the contaminated material, and the material compatibility with the transport system;
- Site access and topography; and
- Control and monitoring of fugitive emissions during transport.

### **A.5.2.2 Slurry Pipeline**

A slurry pipeline consists of a pipeline and pump equipment used to transport soil materials in slurry form. A slurry pipeline requires removal of soils, equipment to generate a slurry from the soil, piping, and pumps to move the slurry to a treatment facility. Slurry pipeline systems are relatively short (because of costs involved) and are used as a component of treatment systems, e.g., soil washing). A slurry pipeline may be used as a temporary or long-term transport system.

The following factors may limit the applicability and effectiveness of the process:

- The distance between the contaminated site and the nearest treatment/disposal facility;
- Quantity of the contaminated material;
- Characteristics of the contaminated material and its compatibility with the transport system;
- Site access and topography;
- Control and monitoring of fugitive emissions during removal and slurry generation; and
- Possible problematic separation and treatment of water from the slurry.

### **A.5.2.3 Truck Hauling**

Contaminated materials can be transported to onsite treatment facilities by various sizes of trucking vehicles and earthmoving equipment. Truck transport may require containerization of contaminated material during transport. A loading process as well as monitoring or control of fugitive emissions may also be required during transport.

The following factors may limit the applicability and effectiveness of the process:

- The distance between the contaminated site and the nearest treatment/disposal facility;
- Quantity of the contaminated material;
- Characteristics of the contaminated material and its compatibility with the transport system;
- Site access and topography; and

- Control and monitoring of fugitive emissions during removal and slurry generation.

### **A.5.3 Long Distance Transport**

Transportation is the physical removal of soil from a site after excavation. Transport actions do not treat contaminants, but provide a means of moving contaminated materials to onsite or offsite treatment facilities. Long distance transport includes processes that move contaminated material across long distances. For example, long distance transport may include transport of contaminated material from the site of removal to treatment or disposal facility. Soils may be placed in drums or rolloff containers prior to transportation. The selection of a specific transport process must consider the distance and purpose of transport. Long distance transport includes primarily truck and/or rail transport.

#### **A.5.3.1 Truck/Rail Hauling**

Contaminated materials can be transported by truck or rail systems. Various sizes of trucking vehicles and earthmoving equipment may be used to transport contaminated materials to onsite or offsite treatment facilities. In-place or constructed rail systems may also be used. Truck or rail transport may require containerization of contaminated material during transport. A loading process as well as monitoring or control of fugitive emissions may also be required during transport.

The following factors may limit the applicability and effectiveness of the process:

- The distance between the contaminated site and the nearest treatment/disposal facility;
- Quantity of the contaminated material;
- Characteristics of the contaminated material and its compatibility with the transport system;
- Site access and topography;
- Control and monitoring of fugitive emissions during removal and slurry generation;
- Applicable U.S. Department of Transportation (DOT) regulations; and
- Community acceptance.

#### **A.5.4 Offsite Storage/Disposal**

Storage of hazardous waste is not a true treatment that reduces toxicity, volume, or mobility of a waste. However, storage occurs prior to treatment and after removal of a waste. Disposal is a broad term to describe treatment of a waste. Landfilling has been the most commonly practiced method of disposing of municipal, industrial, and hazardous wastes. The primary advantage of landfilling is its simplicity compared to other technologies and the ability of landfills to handle large volumes of waste. A hazardous-waste landfill contains and isolates hazardous wastes that are not currently recoverable to ensure present and long-term environmental protection. To accomplish these objectives, the landfill must be planned, designed, constructed, operated, and maintained in accordance with federal, state, and local regulations (Freeman, 1988).

Offsite permanent disposal options include the use of a landfill or other treatment, storage, and disposal (TSD) facility. Offsite storage and disposal require transport of potentially radioactive wastes over public roads or railroads. A permitted commercial TSD facility must also accept responsibility for the waste.

##### **A.5.4.1 Landfill/TSD Facility**

Disposal of hazardous materials at a commercial TSD landfill facility is becoming increasingly difficult because of restrictions on landfilling certain chemicals, restrictions on transportation of hazardous wastes (particularly across state lines), and the high costs charged by commercial disposal facilities to accept wastes.

The following factors may limit the applicability and effectiveness of the process:

- The distance between the contaminated site and the nearest disposal facility;
- Compliance with all federal, state, and local regulations, including but not necessarily limited to, DOT and RCRA regulations;
- Quantity of the contaminated material;
- Characteristics of the contaminated material; and
- Community acceptability.

#### **A.5.5 Onsite Storage/Disposal**

Storage of hazardous waste is not a true treatment that reduces toxicity, volume, or mobility of a waste. However, storage occurs prior to treatment and after removal of a waste. Disposal is a broad term to describe treatment of a waste. Landfills have been the most commonly practiced method of disposing of municipal, industrial, and hazardous wastes. The primary advantage of landfilling is its simplicity compared to other technologies and the ability

156

of landfills to handle large volumes of waste. A hazardous-waste landfill contains and isolates hazardous wastes that are not currently recoverable to ensure present and long-term environmental protection. To accomplish these objectives, the landfill must be planned, designed, constructed, operated, and maintained in accordance with federal, state, and local regulations (Freeman, 1988).

Onsite disposal may be long-term or short-term, and is dependent on storage and disposal permit requirements. Disposal vaults and container storage may be the most practical onsite storage processes. Container storage is not a permanent treatment, but may be used to stage wastes for onsite treatment or prior to transport after removal. A disposal vault may also be a viable storage option depending on characteristics of the waste.

#### **A.5.5.1 Disposal Vault**

Disposal vaults are designed as retrievable, monitored containment structures for temporary storage of hazardous or mixed wastes. Disposal vaults can be aboveground or underground, using aboveground landfill design technology, or underground entombment structures. Concrete vaults with covers may be considered for underground entombment structures. Waste can be retrieved more easily when recovery, destruction, or detoxification proves to be technically or economically feasible.

#### **A.5.5.2 Container Storage**

Hazardous materials can be held in drums or specifically designed containers until cost-effective treatment or disposal is carried out. Drums are cylindrical shipping containers for solids and liquids; they have a storage capacity of 12 to 110 gallons. A drum for storage of hazardous waste material must achieve minimum DOT standards. Drums can be metal, fiberboard, or plastic, depending upon compatibility and structural requirements. Containers can also include structural holders of material (e.g., roll-off containers and dumpsters).

#### **A.5.5.3 Permitted Landfill**

The time associated with construction and operation of an onsite landfill is much shorter than for many treatment options. Landfills are classified based on their cover and liner systems and the types of wastes that may be disposed of in them. Depending on the concentrations and leachability of contaminants, contaminated soil and sediments could be placed in either an onsite hazardous waste landfill that is constructed according to the RCRA technology requirements or in an onsite industrial/municipal-type landfill.

A typical hazardous waste landfill is constructed with a lower liner system consisting of at least one synthetic and one low-permeability clay liner, and a leachate collection and leak detection system. A network of monitoring wells is also placed around the perimeter of the landfill. The cover system consists of one or two synthetic or clay liners, a gas-collection

system and an infiltration-drainage system. In some instances a leak-detection system is also included in the cover system.

Industrial landfills are designed and operated similarly to RCRA hazardous waste landfills; however, industrial landfills accept only non-RCRA hazardous wastes. Liquids, reactive wastes, and other highly toxic wastes are also banned from industrial landfills. Municipal landfills are more simply constructed and, therefore, are suitable to receive only nonhazardous wastes. These landfills generally receive all wastes associated with municipalities, specifically excluding hazardous, agricultural, and mining wastes.

The following factors may limit the applicability and effectiveness of the process:

- Quantity of the contaminated material;
- Characteristics of the contaminated material;
- Compliance with all federal, state, and local regulations, including but not necessarily limited to, DOT and RCRA regulations;
- Site hydrogeologic, geologic, and weather conditions affecting the location, design, construction, operation, and maintenance of the landfill; and
- Community acceptability.

## **A.6            *EX SITU* TREATMENT**

*Ex situ* treatment requires excavation or removal of the contaminated soil or sediment prior to treatment. Direct treatment technologies include a wide range of processes that can reduce the toxicity, mobility, or volume of inorganic and organic contaminants in soil. The direct treatment technologies are discussed and grouped by biological, physical/chemical, and thermal processes.

### **A.6.1            Chemical/Physical Treatment**

Physical treatment is a process in which the hazardous constituent is separated from its carrier by various physical methods such as adsorption, distillation, and filtration. Physical treatment is applicable to a wide variety of wastes, but further treatment is usually required. For this reason, physical treatment is often discussed along with chemical treatment.

Chemical treatment is a process in which the hazardous constituent is altered by a chemical reaction that reduces or eliminates the toxicity of the contaminant. Wastes that can be treated by this method include both organic and inorganic compounds. Drawbacks to this method are that impurities in the waste may inhibit the treatment process reaction and hazardous

byproducts may be generated. The major direct physical/chemical treatment technologies include: dehalogenation, reduction/oxidation, soil vapor extraction, soil washing, and solvent extraction.

#### **A.6.1.1 Chemical Reduction/Oxidation (Red/Ox)**

Reduction/oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The reducing/oxidizing agents most commonly used for treatment of hazardous contaminants are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide. These reagents may be used in combination or with ultraviolet light to improve reduction/oxidation effectiveness. Chemical reduction/oxidation has been applied at both industrial and hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

- Incomplete oxidation or formation of intermediate contaminants may occur depending upon the contaminants and oxidizing agents used;
- The process may not be cost-effective for high contaminant concentrations due to the large amounts of oxidizing agent required; and
- Oil and grease in the media should be minimized to optimize process efficiency.

The target contaminant group for chemical reduction/oxidation is inorganics. The technology can be used but may be less effective against non-halogenated volatile and semivolatile organic compounds, petroleum hydrocarbons, and pesticides. Excavation associated with chemical reduction/oxidation poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations.

The overall cost for this technology should be in the range of \$100-\$300/ton. Chemical reduction/oxidation is not considered to be either capital- or O&M-intensive.

#### **A.6.1.2 Soil Washing**

Contaminants sorbed onto soil particles are separated from soil in an aqueous-based system. This often requires preliminary application of a physical separation process prior to soil washing. Organics amenable to water washing can be identified according to their soil/water partition coefficient, or estimated using their octanol/water partition coefficient. The wash water may be combined with a basic leaching agent, surfactant, acid or base for pH adjustment, or chelating agent to help remove organics or heavy metals. The solution is treated to remove the contaminants after the soil particles have been removed by precipitation or dewatering. Recovery and reuse of the reagents used in this process may be difficult. Soil washing has been successfully implemented to treat soils from both industrial and hazardous waste sites.

157

The following factors may limit the applicability and effectiveness of the process:

- Fine soil particles (silts, clays) are difficult to remove from washing solutions;
- Complex waste mixtures (e.g., metals with organics) make formulating washing solutions difficult; and
- High humic content in soil inhibits desorption.

The target contaminant groups for soil washing are halogenated and non-halogenated semivolatile organic compounds, petroleum hydrocarbons, and inorganics. The technology can be used on all contaminant groups but may be less effective on halogenated and non-halogenated volatile organic compounds and pesticides. The technology offers the potential for recovery of metals and can clean a wide range of organic and inorganic contaminants from coarse-grained soils. Excavation associated with soil washing poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations.

Average cost for use of this technology, including excavation, is approximately \$120-\$200 per ton (\$132-\$220/metric ton) and is dependent on the type of contamination and concentrations. Soil washing is considered to be both capital- and O&M-intensive.

#### **A.6.1.3 Solvent Extraction**

Waste and solvent are mixed in an extractor, dissolving the organic contaminants into the solvent. The extracted organics and solvent are then placed in a separator, where the contaminants and solvent are separated for treatment and further use (McCoy, 1989). The process can be operated continuously. Solvent extraction has been applied at both industrial and hazardous waste sites, and is being tested at RFETS to determine its effectiveness in removing radionuclides.

The following factors may limit the applicability and effectiveness of the process:

- Organically bound metals can be extracted along with target organic pollutants;
- The presence of detergents and emulsifiers can influence the extraction performance;
- Traces of solvent may remain in the treated solids;
- The toxicity of the solvent is an important consideration;

- Solvent extraction is generally least effective on very high molecular weight organic and very hydrophilic substances; and
- Some soil types and moisture content levels will adversely impact process performance.

The target contaminant groups for solvent extraction are halogenated and non-halogenated semivolatile organic compounds and pesticides. The technology can be used to treat halogenated and non-halogenated volatile organic compounds, and petroleum hydrocarbons, but it may not be as effective or applicable to all of these compounds. Excavation associated with solvent extraction poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations.

The overall cost for this technology is expected to be greater than \$300/ton. Solvent extraction is considered to be both capital- and O&M-intensive.

#### **A.6.1.4 Electrokinetics**

Electrokinetics is used to decontaminate soils by applying an electric field to facilitate the transport of liquids through soils. See Section A.4.2.4. The process is applied to *in situ* soil; however, the process can also be applied to an excavated or stockpiled quantity of soil.

#### **A.6.1.5 Physical Separation**

Physical separation of a contaminated soil is the process of separation by which components of the soil are removed from each other using gravity, circular acceleration, filters or sieves, and vibration, without the application of chemicals or treatment of the contaminated soils.

#### **A.6.1.6 Magnetic Separation**

Magnetic separation uses the magnetic properties of metal contaminants to remove them from contaminated soils. High-gradient magnetic separation relies on a strongly magnetic seeding agent such as magnetite to capture paramagnetic materials such as oxides of iron, manganese, copper, chromium, cobalt, and nickel. In the process, precipitation products, suspended solids, and the magnetite form a coagulum that is later removed.

#### **A.6.1.7 Dehalogenation**

Dehalogenation is the treatment process to remove unwanted halogens (e.g., F, Cl, Br, I) from compounds to make them less toxic or to facilitate further treatment. Two major examples of dehalogenation include: base-catalyzed decomposition and glycolate.

161

**A.6.1.7.1 Base-Catalyzed Decomposition.** Base-catalyzed decomposition (BCD) is a dehalogenation/dechlorination process that strips off chloride in the PCB molecule and forms sodium chloride and biphenyls. Contaminated soil is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate. The mixture is heated to 630°F (333°C) in a rotary reactor to decompose and partially volatilize the contaminants. Dehalogenation (BCD) is a full-scale technology, but has had very limited use.

The following factors may limit the applicability and effectiveness of the process:

- If the influent matrix includes heavy metals and certain non-halogenated volatiles, they will not be destroyed by the process; and
- High clay and moisture content will increase treatment costs.

Halogenated semivolatile organic compounds and pesticides are the target contaminant groups for dehalogenation (BCD). The technology can be used to treat halogenated volatile organic compounds, but may be less effective and applicable to only some compounds within this group. The dehalogenation (BCD) process was developed by EPA's Risk Reduction Engineering Laboratory (RREL), in cooperation with the Naval Civil Engineering Laboratory (NCEL), as a clean, inexpensive way to remediate soils and sediments contaminated with chlorinated organic compounds, especially PCBs. The excavation associated with BCD poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations.

Cost of this process is estimated at \$256 per ton. Inadequate information exists as to whether this technology is capital- or O&M-intensive.

**A.6.1.7.2 Glycolate.** An alkaline polyethylene glycolate (APEG) reagent is used to dehalogenate halogenated aromatic compounds in a batch reactor. Potassium polyethylene glycolate (KPEG) is the most common APEG reagent. Contaminated soils and the reagent are mixed and heated in a treatment vessel. In the APEG process, the reaction causes the polyethylene glycol to replace halogen molecules and render the compound non-hazardous. For example, the reaction between chlorinated organics and KPEG causes replacement of a chlorine molecule and results in a reduction in toxicity. Dehalogenation (glycolate) is a full-scale technology.

The following factors may limit the applicability and effectiveness of the process:

- The technology is generally not cost-effective for large waste volumes. Media water content above 20 percent requires excessive reagent volume;
- Concentrations of chlorinated organics greater than 5 percent require large volumes of reagent; and

- The resultant soil has poor physical characteristics.

Halogenated semivolatile organic compounds and pesticides are the target contaminant groups for glycolate dehalogenation. The technology can be used but may be less effective against selected halogenated volatile organic compounds. APEG dehalogenation is one of the few processes available that has been successfully field tested in treating PCBs. The technology is amenable to small-scale applications. Excavation associated with dehalogenation (APEG/KPEG) poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations.

The overall costs for the process are greater than \$300/ton. Dehalogenation (glycolate) is considered to be both capital- and O&M-intensive.

#### **A.6.1.8 Soil Vapor Extraction**

Soil vapor extraction (SVE) applies a vacuum to a network of aboveground piping placed in the excavated media to encourage volatilization of organics. The process includes a system for handling off-gases. The process is very similar to *in situ* SVE and may be enhanced by the addition of thermal energy. Soil vapor extraction has been successfully applied to soils containing hazardous compounds.

The following factors may limit the applicability and effectiveness of the process:

- High humic content of soil inhibits volatilization; and
- The technology is incompatible with certain soil types.

The target contaminant groups for SVE are halogenated and non-halogenated volatile organic compounds. An advantage of the technology over its *in situ* counterpart is the increased number of passageways formed via the excavation process. Excavation associated with SVE poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations.

The overall cost for SVE is under \$100/ton (\$110/metric ton), including the cost of excavation, but excluding treatment of off-gases. SVE is not considered to be either capital- or O&M-intensive.

#### **A.6.2 Biological**

Biological treatment processes use naturally occurring micro-organisms, such as bacteria, fungi, or yeast, to degrade harmful chemicals into less toxic or nontoxic compounds. Micro-organisms, like all living organisms, need nutrients (such as nitrogen, phosphate, and trace

metals), carbon, and energy to survive. Micro-organisms break down a wide variety of organic (carbon-containing) compounds found in nature to obtain energy for their growth. Biological processes can use natural process to promote the growth of micro-organisms that can degrade contaminants and convert them to less toxic or nontoxic byproducts.

#### **A.6.2.1 Biological Leaching**

Biological leaching is a process intended to solubilize plutonium from soils. Soils have been subjected to bench-scale treatability studies. The process uses thiobacillus amendments to assist with plutonium solubilization. Available data have indicated removal of americium and plutonium from soils of up to 88 percent. Test results indicate that since the soils were not sterilized, native microbes may have competed with the proprietary microbes, and a greater percentage of radionuclide removal may be possible.

#### **A.6.3 Solidification/Stabilization**

Solidification/stabilization has been implemented at industrial and hazardous waste sites. Contaminants are physically bound or enclosed within a stabilized mass (solidification), and/or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility.

The following factors may limit the applicability and effectiveness of the process:

- Environmental conditions may affect the long-term immobilization of contaminants;
- Some processes can result in up to double the original volume;
- Certain wastes are incompatible with solidification/stabilization processes; and
- Treatability studies may be required.

The target contaminant group for solidification/stabilization is inorganics. The technology has limited effectiveness against halogenated and non-halogenated semivolatile organic compounds and pesticides. However, processes designed to be more effective against organic contaminants are being developed and tested. Solidification/stabilization is relatively simple, uses readily available equipment, and has high throughput rates compared to other technologies. Excavation associated with solidification/stabilization poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations.

Data from more than a dozen vendors indicate an approximate cost of under \$100/ton (\$110/metric ton), including excavation. Solidification/stabilization is considered capital-

164

intensive. Solidification/stabilization technologies include: pozzolanic-based agent solidification, cement-based solidification, and proprietary agent-based solidification.

#### **A.6.3.1      Stabilization**

Stabilization refers to a process by which a waste is converted to a more chemically stable form. The term may include solidification and the use of a chemical reaction to transform the toxic component to a new, nontoxic compound. Biological processes, however, are not considered. Stabilization or solidification is often accomplished using proprietary agents to react with or bind wastes under *ex situ* conditions.

Most proprietary processes are protected from unauthorized use by patent or copyright laws. Several proprietary agent processes are very similar and, therefore, extensive bench-scale testing is advisable. Acceptable results from testing of more than one process can achieve cost savings through competitive pricing.

#### **A.6.3.2      Encapsulation**

Encapsulation is a process involving the complete coating or enclosure of waste particles individually (microencapsulation) or as an agglomerated mass (macroencapsulation). The process is typically performed on excavated and/or already treated or drummed wastes. Organic binders include organic substances such as epoxys, polyesters, asphalt, polyethylene, and urea formaldehyde. Organic binders have been used in conjunction with inorganic binders used in cementitious stabilization. The encapsulation process is performed similarly to the cementitious stabilization process.

This process is applicable to all types of toxic contaminants including radionuclides depending on the binder's compatibility with the waste. Worked performed at RFETS, (Faucette et. al., 1992), (Faucette, 1993) demonstrate that polyethylene-encapsulated radioactive waste form will remain chemically and mechanically stable under any conceivable transportation and storage environment. In addition, macroencapsulation is the RCRA "Method of Treatment" for radioactive lead metal. Overmixing or undermixing has been identified as a potential problem and treatability studies are required to ensure the material's compatibility.

#### **A.6.3.3      Cementation**

Cement-based solidification is a specialized form of pozzolanic solidification/stabilization. The type of cement used for solidification/stabilization can be selected to emphasize a particular cementing reaction (EPA, 1986). Pozzolans are frequently added to cement to react with any free calcium hydroxide and thus improve the strength and chemical resistance of the final product. Although much of the pozzolan in waste processing may be inactivated by the waste, any reaction that does occur between the cement and free silica from the pozzolan adds to the product strength and durability.

165

Cement/fly ash processes typically require the use of sorbents or other additives to stabilize and, therefore, decrease, the loss of specific hazardous materials from the porous, solid products. Such adaptations of the technology are also often necessary because some materials inhibit the binding action in cement. This process is used extensively for contaminated soil treatment.

Pozzolan-based solidification utilizes materials that set into a solid mass when mixed with hydrated lime. Pozzolan materials include hydrated silicic acid, diatomaceous earth, blast furnace slag, ground brick, and some fly ashes. Solidification/stabilization of wastes using lime and pozzolan materials requires mixing the wastes to a pasty consistency with a carefully selected pozzolan. Hydrated lime (calcium hydroxide) is then blended into the waste-pozzolan mixture. The resulting moist material is packed into a mold to cure, is backfilled, or is placed in a landfill and compacted.

Impurities such as organics, silt, and soluble salts may delay curing and setup of the matrix and may reduce strength and durability. In addition, additives increase the weight and bulk of the matrix. The technology and management of cement mixing and handling are well known, as is the chemistry of lime reactions. However, bench- and pilot-scale testing are usually warranted. Pozzolan-based solidification is widely used for treatment of contaminated soils.

#### **A.6.3.4      Vitrification**

Contaminated soils and sludges are melted at high temperature to form a glass and crystalline structure with very low leaching characteristics. Non-volatile inorganic elements are encapsulated in a vitreous slag while organic contaminants are destroyed by pyrolysis.

The following factors may limit the applicability and effectiveness of the process:

- Organic and inorganic off-gases need to be controlled;
- Use or disposal of the resultant vitrified slag is required; and
- Accessibility to a sufficient power supply is needed.

Vitrification is applicable to the full range of contaminant groups, but inorganics are the target contaminant group. Metals are encapsulated in the vitrified mass, resisting leaching for geologic time periods. Excavation associated with vitrification poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations. The high energy required for vitrification process may constitute a health and safety concern.

166

Approximate overall cost is \$700/ton (\$770/metric ton). Vitrification is a relatively complex technology that requires excessive energy and trained personnel. Vitrification is considered to be both capital- and O&M-intensive.

#### **A.6.4 Thermal Treatments**

This treatment process involves decomposition of hazardous compounds by thermal means into less hazardous or non-hazardous components. Thermal energy can be used to combust or burn contaminants, or volatilize contaminants. When subjected to high temperatures, organic compounds decompose to similar, less toxic forms. Complete combustion yields carbon dioxide and water plus small amounts of carbon monoxide, nitrous oxides, and chlorine and bromine acid gases. Some thermal processes produce off-gases and ash that require further treatment or landfill disposal. Thermal treatment is most suitable for organic wastes and is less effective when attempting to detoxify heavy metals and inorganic compounds. One drawback of thermal treatment is the high cost involved. The major types of direct thermal treatment technologies include: incineration, desorption, thermal distillation, and pyrolysis.

##### **A.6.4.1 Incineration**

High temperatures, 1600°-2200°F (871°-1204°C), are used to volatilize and combust (in the presence of oxygen) organic constituents in hazardous wastes. Seven common incinerator designs are fluidized bed, infrared, rotary hearth, rotary kiln, slagging, fixed hearth, and circulating-bed. The destruction and removal efficiency (DRE) for properly operated incinerators often exceeds the 99.99 percent requirement for hazardous waste and can be operated to meet the 99.9999 percent requirement for PCBs and dioxins. All seven incinerator types have been implemented successfully to treat both industrial and hazardous wastes.

The following factors may limit the applicability and effectiveness of the process:

- There are specific feed size and materials handling requirements that can impact applicability or cost at specific sites;
- The presence of volatile metals and salts may affect performance or incinerator life;
- Volatile metals, including lead and arsenic, leave the combustion unit with the flue gases or in bottom ash and may have to be removed prior to incineration;
- Metals can react with other elements in the feed stream, such as chlorine or sulfur, forming more volatile and toxic compounds than the original species; and
- Sodium and potassium can attack the brick lining and form a sticky particulate that fouls heat transfer surfaces.

The target contaminant groups for incineration are all halogenated and non-halogenated semivolatile organic compounds and pesticides. The technology also may be used to treat halogenated and non-halogenated volatile organics and fuels but may be less effective. Excavation associated with incineration poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations. If an offsite incinerator is used, the potential risk of transporting the hazardous waste through the community must be considered.

Incineration costs are highly dependent upon the size of the contaminated site and the type of incinerator technology used. The cost to incinerate approximately 20,000 tons (18,200 metric tons) of contaminated media would be greater than \$300/ton (\$330/metric ton).

The capital expenditure associated with incinerators is relatively high. Materials handling, control of bed temperatures and residence times, and system maintenance make the technology O&M-intensive as well.

**A.6.4.1.1 Fluidized Bed.** The fluidized-bed incinerator consists of a refractory-lined vessel containing a bed of inert, granular, sand-like material. Solids, sludges, and liquids can be injected directly into the bed or at its surface. If contaminated solid is being processed, the soil mass acts as the bed material and it must be crushed to a sized less than 1 inch in diameter. In operation, combustion air is forced upward through the bed, which fluidizes the material at a minimum critical velocity. The heating value of the wastes, plus added fuel, maintains the desired combustion temperature in the vessel. The heat of combustion is transferred back into the bed, and the agitated mixture of waste, fuel, and hot bed material in the presence of fluidizing air provides a turbulent combustion environment.

The use of a large volume of heated bed material resists short-term fluctuations in temperature and retention time due to changes in moisture, ash, or British Thermal Unit (BTU) content of the waste. Fluidized-bed incinerators can be operated at lower temperatures than other incinerators because of the high mixing energies aiding the combustion process. This mixing offers the highest thermal efficiency while minimizing auxiliary fuel requirements and volatile metal emissions. The maximum operating temperature is limited by the fusion temperature of the sand fluidizing materials.

**A.6.4.1.2 Infrared Furnace.** Infrared thermal units use silicon carbide elements to generate thermal radiation beyond the red end of the visible spectrum. Materials to be treated pass through the combustion chamber on a belt and are exposed to the radiant heat. Waste material should be less than 2 inches in diameter for optimal efficiency. In the combustion chamber, wastes can be either incinerated or pyrolyzed at 1400°F or 800°C. Off-gases flow to a gas-fired secondary combustion chamber that provides complete destruction. Flue gas treatment is accomplished by any conventional off-gas cleanup system.

Soils contaminated with PCBs, dioxin, and a variety of other wastes have been treated at pilot- or full-scale facilities using infrared electric furnaces. The current availability of this technology is uncertain.

**A.6.4.1.3 Molten Salt Incineration.** A molten salt incinerator consists of a metal containment vessel containing sodium carbonate salts. The exterior of the containment vessel is heated with a gas burner or other suitable heat source to establish a molten salt bath at 1600 to 1800 °F. Liquid or solid waste along with combustion air are injected into the salt bath through a downcomer. The air waste and combustion products bubble through the molten salt and are decomposed. Exhaust gases react with the salt, eliminating the need for a downstream scrubbing system, and inert gases are released through a port in the top of the vessel.

Inorganic reaction products build up in the melt and must be removed. This process is not suitable for high ash content waste such as soils because the fluidity of the melt will be adversely affected when ash content reaches 20 percent by weight. Melt is withdrawn from the melt overflow, after which it is allowed to solidify before final disposal. Molten salt incinerators are not commercially available for hazardous waste applications, although pilot-scale units (as large as 200 pounds per hour) have been developed for coal gasification research (RMA, 1992).

**A.6.4.1.4 Solar Incineration.** Solar incineration uses an array of focused heliostats to concentrate the radiant energy from the sun into a reactor containing the material being processed. The very high temperatures produced result in high destruction and removal efficiencies. Removal efficiencies as high as 99.999 percent have been achieved. The process is considered innovative and the required equipment is not readily available. The amount and intensity of sunshine affect the implementability of this process.

**A.6.4.1.5 Rotary Hearth or Multiple Hearth.** A rotary hearth incinerator consists of a vertical refractory-lined steel shell, a rotating central shaft, a series of solid flat hearths, a series of rabble arms with teeth for each hearth, an air blower, waste feed and ash removal systems, and fuel burners mounted on the walls. The waste falls from the top hearth to subsequent hearths until it reaches the bottom hearth, where it is discharged as ash. Rotary hearths can also be equipped with an afterburner, liquid waste burners, and side ports for tar injection. The temperature in the burning zone ranges from 1400 to 1900°F, and residence times may be long compared to other incinerators.

This incinerator is best suited for hazardous sludge destruction. Solid waste often requires pretreatment such as shredding and sorting. This process can treat the same wastes as a rotary kiln, provided that the solid waste is pretreated. The principal advantages of rotary hearth incineration include high residence time for sludge and low-volatility materials and high fuel efficiency, and ability to handle a variety of sludges, ability to evaporate large amounts of water, and the ability to use a variety of fuels.

**A.6.4.1.6 Microwave Melting.** Microwave melting includes the transmission of high-energy microwaves into contaminated material. The microwaves are absorbed by the contaminated material to produce a non-leachable vitrified mass. This process is considered innovative, and is still in the development stage. Off-gas treatment and containment are required for this process. This process is considered time- and energy-intensive. Homogeneous wastes with a high silica content produce the most favorable final results. Non-uniform melting can result, leaving portions of the waste untreated.

**A.6.4.1.7 Rotary Kiln.** Rotary kiln incinerators are slightly inclined, refractory-lined cylinders. Rotary kiln incineration involves the controlled combustion of organic wastes under oxidizing conditions. Contaminated soils are typically fed either continuously or on a batch basis (using a waste storage hopper) into the high end of the kiln and passed through the combustion zone as the kiln rotates. Auxiliary fuel is added either to the high end (co-fired) or low end (counterfired) of the kiln. An enriched oxygen supply system is often included to enhance incineration. Rotation of the combustion chamber creates turbulence and improves the degree of burnout of the solids, and wastes are substantially oxidized to gases and inert ash within this zone. Retention time can vary from several minutes to an hour or more, and is controlled by feed rate, inclination, and speed of rotation. Ash and slag are collected in an ash bin located at the rear of the kiln. Partial volatilization of some inorganics occurs in the primary chamber.

Off-gas is directed to a secondary combustion afterburner that is a refractory-lined chamber. Sufficient residence time and combustion temperature in the afterburner provide for the complete destruction of any unburned organics in the combustion gases leaving the kiln. Typical temperatures required for nearly complete destruction of a wide range of hazardous wastes range from 1800 to 2250°F in the afterburner. A liquid scrubber is used to quench effluent gases, remove particulates including volatile inorganic contaminants, and neutralize any acids that may be produced. Scrubber effluent that is not recycled generally requires neutralization, clarification, or other wastewater treatment prior to discharge.

Although organic-solids combustion is the primary use of rotary kiln incinerators, liquid and gaseous organic wastes can also be handled by injection into either the feed end of the kiln or the secondary combustion chamber. Rotary kilns are currently most commonly used for hazardous solid waste incinerators. There are many vendors of transportable units ranging in size from 1 to 60 tons-per-hour throughput (Johnson, 1993). Wastes containing high quantities of caustic can result in excess slag formation, which can build up and hamper kiln performance.

**A.6.4.1.8 Oxygen-Enhanced Incineration.** Oxygen enhanced incineration is a thermal destruction process using an integrated combustion system that uses a new technique for mixing auxiliary fuel, oxygen, and air. Specific removal efficiencies are unknown. This incineration achieves a reduction in the toxicity and volume of the waste stream, and has the ability to incinerate double the waste throughput possible with conventional incineration, without an increase in carbon monoxide level emissions. Required equipment is commercially available.

The following factors may affect the applicability and effectiveness of the process:

- Most effective for wastes with low heating values; and
- Permitting and public acceptance may be difficult.

**A.6.4.1.9 Liquid Injection.** Liquid injection incineration includes atomizing nozzles injecting contaminated fluid into a refractory lined combustion chamber. Liquid injection can achieve destruction efficiencies greater than 99 percent, reducing the toxicity and volume of waste. Liquid injection equipment is commercially available; however, no units are currently in operation.

The following factors may limit the applicability and effectiveness of the process:

- Produces off-gas which requires treatment;
- Supplemental fuel would be required;
- Energy intensive; and
- Permitting and public acceptance may be difficult.

**A.6.4.1.10 High Temperature Fluid Wall.** This process uses a reactor consisting of a porous carbon core surrounded by carbon electrodes that heat the core to 4000 to 5000 °F. Wastes pass through the core by gravity flow and are quickly incinerated. A nitrogen gas blanket (or fluid wall) prevents the waste from contacting the core walls. This process can achieve a removal efficiency of 84.9 percent and above. Commercial high temperature fluid wall units are available, but are untested.

The following factors may limit the applicability and effectiveness of the process:

- Off-gas from the process requires treatment;
- This process is considered innovative;
- High operation and maintenance costs may be incurred during for this process.

#### **A.6.4.2 Low-Temperature Thermal Desorption**

Thermal desorption is a physical separation process that is not designed to destroy organics but to volatilize (desorb) them from the waste. Typically a carrier gas or vacuum system transports volatilized water and organics to a gas treatment system. For low temperature thermal desorption, wastes are heated from 200°-600°F (93°-315°C) to volatilize water and

organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system. Low temperature thermal desorption systems are physical separation processes and are not designed to destroy organics. The bed temperatures and residence times designed into these systems will volatilize selected contaminants, but typically will not oxidize them. Low temperature has been implemented to treat industrial and hazardous wastes.

The following factors may limit the applicability and effectiveness of the process:

- There are specific feed size and materials handling requirements that can impact applicability or cost at specific sites;
- Dewatering may be necessary to achieve acceptable soil moisture content levels; and
- Highly abrasive feeds can potentially damage the processor unit.

The target contaminant groups for low temperature thermal desorption systems are halogenated and nonhalogenated volatile organic compounds and petroleum hydrocarbons. The technology can be used to treat halogenated and non-halogenated semivolatile organic compounds and pesticides, but may be less effective. Excavation associated with low temperature thermal desorption poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations.

Approximate overall cost is less than \$100/ton (\$110/metric ton). Low temperature thermal desorption is relatively labor-intensive. The skill and training level required for most of the operating personnel is minimal. Low temperature thermal desorption is considered to be both capital- and O&M-intensive.

#### **A.6.4.3 HT-5 Thermal Distillation Process**

This process heats wastes in a nitrogen atmosphere to vaporize volatile and semivolatile compounds. The resulting hot gases are condensed to recover liquified hydrocarbon products. Some pilot- and full-scale testing has been performed to evaluate this process. The equipment required for this process is available.

The following factors may limit the applicability and effectiveness of the process:

- Removal efficiencies are unknown;
- The organic content of the waste stream;

- Process requires supplemental heating and cooling/refrigeration and capital costs for the purchase of nitrogen; and
- Process is considered innovative.

#### **A.6.4.4 Pyrolysis**

Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash. Pyrolysis is currently under development.

The following factors may limit the applicability and effectiveness of the process:

- There are specific feed size and materials handling requirements that impact applicability or cost at specific sites; and
- The technology requires a low soil moisture content. Highly abrasive feed can potentially damage the processor unit.

The target contaminant groups for pyrolysis are all halogenated and non-halogenated semivolatile organic compounds and pesticides. The technology also may be used to treat halogenated and nonhalogenated volatile organics and fuels, but may be less effective. Excavation associated with pyrolysis poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, normally would be required during excavation operations.

Overall cost of remediating approximately 20,000 tons (18,200 metric tons) of contaminated media is expected to exceed \$300/ton (\$330/metric ton). Pyrolysis is considered to be both capital- and O&M-intensive.

## **APPENDIX B**

### **DESCRIPTION OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS PASSING THE TECHNICAL IMPLEMENTABILITY SCREEN**

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## APPENDIX B TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
B.1 NO FURTHER ACTION .....	B-1
B.1.1 Intrinsic Remediation .....	B-1
B.1.1.1 Groundwater Monitoring .....	B-2
B.2 INSTITUTIONAL CONTROLS .....	B-2
B.2.1 Access Restrictions .....	B-3
B.2.1.1 Fencing, Security .....	B-3
B.2.1.2 Lock Out/Tag Out Wells .....	B-3
B.2.2 Land Use Restrictions .....	B-3
B.2.2.1 Deed Restrictions .....	B-3
B.2.2.2 Zoning Restrictions .....	B-4
B.2.2.3 Regulatory Restrictions .....	B-4
B.3 CONTAINMENT .....	B-4
B.3.1 Surface Water Controls .....	B-5
B.3.1.1 Enhanced Soil Treatment, Revegetation, Grading, and Compaction .....	B-5
B.3.2 Groundwater Controls .....	B-5
B.3.2.1 Extraction Wells .....	B-6
B.3.2.2 Interceptor Trenches .....	B-6
B.3.3 Vertical Barriers .....	B-7
B.3.3.1 Sheet Piling .....	B-7
B.3.3.2 Slurry Walls .....	B-7
B.3.3.3 Synthetic Membrane Cutoff Wall .....	B-8
B.3.4 Horizontal Barriers .....	B-9
B.3.4.1 Asphalt-Based Cover .....	B-9
B.3.4.2 Compacted Clay Cover .....	B-9
B.3.4.3 Multi-layer Cover .....	B-10
B.4 REMOVAL .....	B-11
B.4.1 Groundwater Extraction .....	B-11
B.4.1.1 Extraction Wells .....	B-11
B.4.1.2 Interceptor Trenches .....	B-11
B.4.2 Groundwater Transport .....	B-11
B.4.2.1 Truck/Rail Hauling .....	B-12
B.4.2.2 Pipeline .....	B-12

## APPENDIX B

### TABLE OF CONTENTS (Continued)

B.4.3	Disposal .....	B-12
B.4.3.1	RFETS Sewage Treatment Plant .....	B-13
B.5	<i>IN SITU</i> TREATMENT .....	B-13
B.5.1	Biological Treatment .....	B-13
B.5.1.1	Enhanced Anaerobic Bioremediation .....	B-13
B.5.1.2	Co-Metabolic Processes .....	B-14
B.5.2	Chemical/Physical Treatments .....	B-15
B.5.2.1	Air Sparging .....	B-15
B.5.2.2	Passive Treatment Walls .....	B-16
B.5.3	Thermal .....	B-17
B.5.3.1	Thermally Enhanced Soil Vapor Extraction .....	B-17
B.6	<i>EX SITU</i> TREATMENTS .....	B-18
B.6.1	Chemical/Physical .....	B-18
B.6.1.1	Onsite Water Treatment Plant .....	B-18

## DESCRIPTION OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS PASSING TECHNICAL IMPLEMENTABILITY

This section provides a description of the technologies for the remediation of contaminated groundwater at RFETS. The technologies included in this section cover the range of options and approaches available to treat contaminated groundwater or otherwise protect human health and the environment. These technologies, alone or combined, have been in the development of alternatives to satisfy the Corrective/Remedial Action Objectives (C/RAOs). EPA documents, engineering reference materials, technical journals, periodicals, and reference data bases were used to develop these technology descriptions.

The technologies are organized in general by (1) general response action, (2) technology type, and (3) process option. The general response actions are no action, institutional controls, containment, removal, *in situ* treatment, and *ex situ* treatment.

### B.1 NO FURTHER ACTION

No further action provides a baseline exposure risk scenario for comparison with the risks associated with the implementation of other technology types, and is required under CERCLA (EPA, 1988). No action means no activities are conducted nor technologies implemented to address potential groundwater and surface water contamination or interrupt potential human health and environmental exposure pathways.

#### B.1.1 Intrinsic Remediation

Natural processes, such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with natural occurring materials, may reduce contaminant concentrations over time. These processes are referred to as intrinsic remediation, or natural attenuation, and may coincide with no action.

Occurrence of intrinsic remediation is determined by the types of contaminants present and the specifics of the site. Target contaminants for intrinsic remediation are non-halogenated volatile and semivolatile organics and petroleum hydrocarbons. Halogenated volatile and semivolatile compounds and pesticides can also be allowed to naturally attenuate but the process may be less effective and may be applicable only to some of these compounds.

The following factors may limit the applicability and effectiveness of the process:

- No action and intrinsic remediation should be used only in low-risk situations; and
- May require periodic surface water and groundwater monitoring (EPA, 1988) to determine if any changes have taken place in short-term and long-term risks.

### **B.1.1.1 Groundwater Monitoring**

Site-specific characteristics that influence the placement of monitoring wells include the nature of the aquifer (e.g., artesian); characteristics of potential leachate; and groundwater depth, flow rates, and direction of flow. Based on assumptions and data about the characteristics of the site, approximate permeability of soils in the zone of aeration, and directions and velocities of groundwater flow, the maximum probable areal extent of contaminant migration can be estimated as a basis for establishing the position of monitoring wells.

Proper location and installation of monitoring wells are essential to a monitoring program. A minimum of four groundwater monitoring wells are typically installed at a hazardous waste site: one upgradient well and three downgradient wells. However, site hydrogeology is often too complex for only four wells to provide adequate detection of groundwater contamination.

Upgradient wells are placed beyond the upgradient extent of contamination. At least three downgradient wells are located to ensure that releases of hazardous waste or hazardous-waste constituents from the hazardous waste management unit(s) to the uppermost aquifer will be quickly detected. The specific number of wells to be included in a detection system depends on the horizontal spacing between well locations and the vertical sampling interval of individual wells.

## **B.2 INSTITUTIONAL CONTROLS**

Institutional controls reduce exposure to site contaminants through administrative actions and access restrictions. Administrative actions include land use restrictions and monitoring of conditions at the site. The intent of access restrictions is to interrupt exposure pathways. Access restrictions include barriers, fencing, and warning signs.

Institutional controls may be appropriate for sites where the potential for exposure is minimal, or where baseline risks are determined to be low. However, institutional controls may also be selected for highly contaminated sites where the risks to workers or community during remediation would exceed the present risks at the site. In this case, institutional controls could include site access restrictions.

As indicated above, institutional controls may be combined with other response actions into alternatives to satisfy remedial action objectives. For example, if a site is remediated through containment or treatment, institutional controls such as deed restrictions or access restrictions may be implemented during as well as after the site is remediated.

### **B.2.1 Access Restrictions**

Access restrictions, which include fencing, locks, warning signs, and other physical barriers, reduce potential exposures by preventing or limiting access to contaminated areas. Access restrictions can also include guards, lighting, and alarms. The most common access restrictions applicable to humans would be fences around the contaminated area and locks and tags on all existing groundwater wells.

The following factors may limit the applicability and effectiveness of the process:

- Access restrictions may need to be expanded if contaminants migrate; and
- Vertical access restrictions are difficult to establish.

#### **B.2.1.1 Fencing, Security**

Exposure to contaminants would be reduced or eliminated by installing a fence around the entire site. Long-term security would be provided to ensure the public does not enter into the restricted area. Monitoring would need to be performed to ensure the contaminants did not migrate outside the fenced area. If contamination migration occurred, the fenced area may need to be expanded to ensure protection of the public.

#### **B.2.1.2 Lock Out/Tag Out Wells**

To limit exposure of contaminated groundwater from the public, existing groundwater wells would be locked and tagged. The wells would be tagged with an identification marker notifying the public that the well was contaminated. The locking and tagging of groundwater wells would prevent the public from contacting the contaminated groundwater.

### **B.2.2 Land Use Restrictions**

Exposure to contaminants may be reduced or eliminated through land use restrictions. Land use restrictions may be incorporated in deeds or zoning requirements. Often deed and zoning restrictions must be together because deed restrictions indicate what cannot be done and zoning restrictions indicate what can be done. Before deed restrictions may be accomplished, a comprehensive title search would need to be completed to verify "Fee Simple" ownership (i.e., mineral, water, and other inherent rights) of the land.

#### **B.2.2.1 Deed Restrictions**

Exposure to contaminants may be reduced or eliminated by adding restrictions to the property deed that limit the future land use. For example, residential or commercial

179

construction in contaminated areas could be prohibited by defining those areas and adding an appropriate stipulation in the property deed. The contaminants would not be removed, but may be reduced over time by natural attenuation.

The following factors may limit the applicability and effectiveness of the process:

- The mineral, water, or other inherent rights must be purchased if they are owned by another party; and
- Potential present and future legal challenges may cause difficulties.

#### **B.2.2.2 Zoning Restrictions**

Exposure to contaminants may be reduced or eliminated by restricting future land use through zoning ordinances. Zoning restrictions would restrict development or use of the entire property rather than just the contaminated areas. Again, the contaminants would not be removed, but may be reduced over time by natural attenuation.

The following factors may limit the applicability and effectiveness of the process:

- Zoning restrictions may be changed, by public and institutional decree at any time; and
- Potential present and future legal challenges may cause difficulties.

#### **B.2.2.3 Regulatory Restrictions**

A local groundwater regulatory restriction would be obtained to require regulatory review of all groundwater well installation plans in the area. The restriction would prevent any drinking water supply wells from being installed in contaminated parts of the aquifer. This would eliminate the potential exposure pathway to the public from a contaminated drinking water supply.

### **B.3 CONTAINMENT**

Containment interrupts the exposure pathways to contaminated groundwater. Containment reduces the mobility but does not reduce the toxicity or volume of the contaminants. Containment may also prevent or reduce the infiltration/percolation of surface waters to the groundwater, thereby reducing the recharge rate of the aquifer. Containment technologies include surface water controls, and horizontal, vertical, and hydraulic barriers.

180

### **B.3.1 Surface Water Controls**

This containment method uses soil treatment, revegetation, grading, and compaction to create a hydraulic barrier that limits the migration of contaminated surface water. Groundwater controls reduce contaminant mobility, but not contaminant toxicity or volume.

#### **B.3.1.1 Enhanced Soil Treatment, Revegetation, Grading, and Compaction**

The surface of the cover soils would be stabilized to decrease erosion by wind and water and to contribute to the development of a stable surface environment. Vegetation is typically the aesthetically preferred final surface of a capping system. Proper vegetation establishment would reduce the damaging effects from erosion due to wind and surface water runoff. Plants also transmit water from the soil to the atmosphere through evapotranspiration, providing a removal pathway for the water stored in the topsoil. When coordinated with surrounding native species, the plants also provide a pleasant blend with natural surroundings.

Vegetative covers include grading and backfilling the contaminated area with general backfill/topsoil material, planting vegetation, and applying pea gravel.

The following factors may limit the applicability and effectiveness of the process:

- Backfilling and grading provide no hydraulic barriers to prevent infiltration of precipitation into underlying material;
- Soil types and availability of water are critical for development of a vegetative surface;
- Periodic repair and maintenance may be required;
- The process is not usually a long-term containment process; and
- Monitoring and a leak detection system may be required.

### **B.3.2 Groundwater Controls**

This containment method uses extraction wells or interceptor systems to create a hydraulic barrier that limits the migration of contaminated groundwater. Typically, extraction wells are placed at the downgradient edge of the groundwater plume to capture the contaminated groundwater and extract it to the surface. Groundwater controls reduce contaminant mobility, but not contaminant toxicity or volume.

### **B.3.2.1 Extraction Wells**

Movement of contaminated groundwater can be controlled or prevented by use of a specially designed hydraulic system including extraction wells. Extraction systems must have a moderate to high operational flexibility, which allow the system to meet increased or decreased pumping needs. Extraction wells use pumps to raise groundwater to the surface resulting in a cone of depression that forms around each well. Usually a network of extraction wells is used. The network is designed with wells at specific depths and locations to optimize groundwater recovery. In some circumstances, the need to employ directional drilling may be for extraction systems. Directional drilling includes angled boreholes, where surface access may be a problem, or horizontal drilling in which horizontal extraction systems are installed to capture shallow, near-surface groundwater. Directional drilling technologies are becoming more common in remediation systems.

### **B.3.2.2 Interceptor Trenches**

Interceptor trenches include any type of trench or buried conduit to convey liquids (unconfined groundwater) by gravity flow. French drains function essentially like an infinite line of extraction wells. To effectively collect groundwater, french drains must be keyed to the bedrock. The trenches may be excavated to a depth of approximately 30 feet using conventional backhoes and to much greater depths using telescopic backhoes or clamshells. After excavation, a perforated pipe is placed in the trench, and backfilled with clean gravel. If surface water collection is desired the gravel will be open at the surface; if not, the last few feet will be filled with soil and revegetated. Collected water will drain by gravity to a pump station where it will be extracted. This process is also known as interceptor trenches and subsurface drains. Synthetic membrane cutoff walls may also be included in this category and additional information may be found in Section B.3.2.3.

The following factors may limit the applicability and effectiveness of the process:

- These methods are limited to depths which can be excavated;
- Heterogeneous aquifers, low hydraulic conductivity, and shallow hydraulic gradient limit applicability of this process;
- Design of a french drain requires prior delineation of the contaminant plume and knowledge of the aquifer properties; and
- Legal issues regarding water rights may need to be resolved.

### **B.3.3 Vertical Barriers**

Vertical barriers prevent the migration of contaminated water by physically restricting horizontal groundwater flow. These barriers have become the principal means for containment of contaminated plumes that threaten aquifers. Used in combination with groundwater pumping or capping, these barriers must normally be attached or made contiguous (keyed) with another low-permeability geological layer such as bedrock or clay in order to restrict secondary vertical migration of contaminants. The use of barriers is therefore limited to sites where such geological layers are available and accessible or where the bedrock is not heavily fractured. The major types of vertical barriers are: sheet piling, slurry walls, and synthetic membrane cutoff walls.

#### **B.3.3.1 Sheet Piling**

This vertical barrier is installed by driving a sheet of corrugated metal into the ground. Additional sheets of metal can be connected to create one long solid wall around the contaminated area. By placing the metal wall around the contaminated area, it encloses the contaminated groundwater in one location and eliminates contaminant migration. The effectiveness of the sheet piling increases with time as fine-grained soil particles wash into the seams creating a better seal between sheets.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants to a specific area; and
- The technology is not feasible to implement in rocky soils or large areas.

#### **B.3.3.2 Slurry Walls**

These subsurface barriers consist of a vertically excavated trench that is filled with a slurry. The slurry, usually a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and forms a filter cake to reduce groundwater flow. In some cases, soil or cement is added to the bentonite slurry to form a soil-bentonite or cement-bentonite barrier. Slurry walls can be "keyed" to a confining layer of clay or bedrock, or left "hanging" when contaminants do not mix with the groundwater. Slurry walls are often used where the waste mass is too large for practical treatment and where soluble and mobile constituents pose an imminent threat to a drinking water source. They are economical at moderate depths (40 to 70 feet), and have a low water permeability (from  $10^{-5}$  to  $10^{-6}$  cm/sec). Slurry walls have been successfully implemented at hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants to a specific area.
- Soil-bentonite backfills are not able to withstand attack by strong acids, bases, salt solutions, and some organic chemicals. There is some concern regarding the permeability of slurry walls to certain organic compounds.
- There is the potential for the slurry walls to degrade or deteriorate over time.
- The trenches are generally limited to an excavated depth of approximately 30 feet using conventional backhoes. Greater depths, approaching 70 feet, can be achieved using telescopic backhoes or clamshells.

Slurry walls are applicable to the full range of contaminants with no particular target group but are considered to be capital-intensive.

#### **B.3.3.3 Synthetic Membrane Cutoff Wall**

Synthetic membranes are used to form a cutoff wall to divert or contain groundwater. Compatibility testing of the liners with chemical wastes must be performed to determine durability. In order to place a synthetic membrane liner as a vertical barrier, a trench must be dug from the surface to an impervious soil layer, and a drain must be placed in the bottom of the trench to remove excess water. The synthetic membrane must be suspended vertically in the trench, and the trench must be backfilled with sand or other suitable material. To be effective, the liner must be keyed into the underlying impervious barrier. During construction, the trench must remain open to facilitate placement of the liner. Extra precautions must be taken in loose, unconsolidated materials to ensure proper placement of the liner.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants to a specific area;
- Construction, depending on site conditions, may be difficult and the synthetic membrane may become damaged; and
- The trenches are generally limited to an excavated depth of approximately 30 feet using conventional backhoes. Greater depths, approaching 70 feet, can be achieved using telescopic backhoes or clamshells.

### **B.3.4 Horizontal Barriers**

Horizontal barriers are used in conjunction with vertical barriers to contain contaminated groundwater, thereby reducing groundwater exposure pathways to the public. By installing a horizontal barrier, surface water is diverted from the impacted area and does not infiltrate/percolate to the contaminated groundwater. By reducing the infiltration/percolation rate of surface water, the recharge rate of the aquifer is reduced. Horizontal barriers applicable to surface water include asphalt-based cover, compacted clay cover, and multi-layer covers.

#### **B.3.4.1 Asphalt-Based Cover**

An asphalt-based cover involves placing an asphalt layer over a crushed-stone bedding layer directly on the site surface. Before the pavement is placed, the site surface must be compacted and graded to prevent differential settlement. Pavement is subject to cracking through weathering processes, and has not frequently been used for long-term containment of hazardous wastes.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants in a specific area;
- Pavement is susceptible to damage by weather (e.g., sun and the freeze/thaw cycle), plants, and animals;
- Design life may be inappropriate for the contaminants of concern;
- Periodic repair and maintenance may be required;
- The process is not usually a long-term containment process; and
- Monitoring and a leak detection system may be required.

#### **B.3.4.2 Compacted Clay Cover**

Compacted clay is frequently used in single or multiple layers in the final cover system of both hazardous and municipal waste landfills. These cover systems may also be utilized to contain contaminated soils. Bentonite, a natural clay with high swelling properties, is often transported to a site and mixed with onsite soil to produce a low-permeability cover material. Onsite soils can sometimes be compacted to achieve the required permeability of  $1 \times 10^{-7}$  cm/sec or less. Vegetation is typically the final surface of a cover system. Proper vegetation reduces the damaging effects from erosion due to wind and surface water runoff.

785

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants in a specific area;
- The uniformity of compacted soil walls is difficult to control;
- The cover may require large volumes of construction material.
- Weathering (cracking) of the clay cover may require extensive maintenance; and
- Monitoring and a leak detection system may be required.

#### **B.3.4.3 Multi-layer Cover**

Clay, compacted soil, or synthetic membranes are frequently used in single or multiple layers in the final cover system of both hazardous and municipal waste landfills. These cover systems may also be utilized to contain contaminated soils. Bentonite, a natural clay with high swelling properties, is often transported to a site and mixed with onsite soil to produce a low-permeability cover material. Sometimes, onsite soils can be compacted to achieve the required permeability of  $1 \times 10^{-7}$  cm/sec or less. The most common synthetic membrane materials are polyvinyl chloride, polyethylene, butyl rubber, Hypalon®, and neoprene.

An example of a multi-layer cover would consist of the following: (1) a gas-collection layer, (2) a composite hydraulic barrier layer combining a compacted-clay and a flexible-membrane liner, (3) a biotic barrier and drainage layer, (4) a topsoil layer, and (5) a permanent vegetative cover.

The following factors may limit the applicability and effectiveness of the process:

- The technology only contains the contaminants in a specific area;
- The uniformity of compacted soil walls are difficult to control;
- Synthetic membrane materials can be easily damaged by weather, human activity, and animals;
- Synthetic membrane materials can degrade over time and may need to be maintained or replaced; and
- Monitoring and a leak detection system may be required.

## **B.4 REMOVAL**

Groundwater may need to be removed for *ex situ* treatment, to lower the water table, or to contain a groundwater contamination plume. Groundwater may be removed by extraction technologies such as extraction wells or interceptor trenches.

### **B.4.1 Groundwater Extraction**

Groundwater extraction is often used in conjunction with *ex situ* treatment technologies or groundwater control technologies to prevent further contamination of the groundwater. With proper placement and operation, a groundwater extraction system can capture contaminants in groundwater and control migration of contaminated groundwater. Therefore, extraction wells and interceptor trenches can serve both as a groundwater containment technology and as a collection technology.

The following factors may limit the applicability and effectiveness of the process:

- Heterogeneous aquifers, low hydraulic conductivity, and shallow hydraulic gradient limit applicability of groundwater extraction;
- Immiscible contaminants may not be extracted with the groundwater;
- Design of a network requires prior delineation of the contaminant plume and knowledge of the aquifer properties; and
- Legal issues regarding water rights may need to be resolved.

#### **B.4.1.1 Extraction Wells**

A description of extraction wells is provided in Section B.3.1.1.

#### **B.4.1.2 Interceptor Trenches**

A description of interceptor trenches is provided in Section B.3.1.2.

### **B.4.2 Groundwater Transport**

Groundwater may be transported over short distances to an onsite treatment facility with the use of truck/rail hauling or a pipeline system.

#### **B.4.2.1 Truck/Rail Hauling**

Groundwater may be transported by hauling the water in trucks or rail cars to a treatment facility.

The following factors may limit the applicability and effectiveness of the process:

- The distance between the contaminated site and the nearest treatment/disposal facility;
- Quantity of the contaminated material;
- Characteristics of the contaminated material and its compatibility with the transport system; and
- Site access and topography.

#### **B.4.2.2 Pipeline**

A pipeline consists of a pipeline and pump equipment used to transport groundwater. A pipeline requires removal of groundwater, piping, and pumps to move the groundwater to a treatment facility. Due to costs, pipeline systems are relatively short and are used as a component of treatment systems. A pipeline may be used as a temporary or long-term transport system.

The following factors may limit the applicability and effectiveness of the process:

- The distance between the contaminated site and the nearest treatment/disposal facility;
- Quantity of the contaminated material;
- Characteristics of the contaminated material and its compatibility with the transport system; and
- Site access and topography.

#### **B.4.3 Disposal**

Following collection, storage, or treatment, the water must be disposed. Disposal options include the onsite sewage treatment plant.

#### **B.4.3.1 RFETS Sewage Treatment Plant**

The onsite sewage treatment system is currently designed to process domestic sewage, storm water, and some industrial water such as compressor or steam condensate. The system may also except industrial wastes such as cleaning solutions or water in the fire lines on a case-by-case basis. The system is an activated sludge treatment system which will remove organics. The system will not effectively treat metals or radionuclides. The system currently operates at an average flow rate of 70 to 140 gallons per minute (gpm), but may be operated up to 350 gpm.

The following factor may limit the applicability and effectiveness of the process:

- The system will need to be evaluated to ensure that it can treat all of the OU2 COCs.

#### **B.5 IN SITU TREATMENT**

*In situ* treatment technologies described in the following paragraphs involve treating the contaminated groundwater in place until remedial action objectives are met. Applicability of *in situ* methods must generally be established on a site-specific basis by pilot-scale treatability studies. *In situ* treatment includes biological treatment, physical/chemical treatment, and thermal treatment.

##### **B.5.1 Biological Treatment**

Bioremediation uses naturally occurring micro-organisms, such as bacteria, fungi, or yeast, to degrade harmful chemicals into less toxic or nontoxic compounds. Micro-organisms, like all living organisms, need nutrients (such as nitrogen, phosphate, and trace metals), carbon, and energy to survive. Micro-organisms break down a wide variety of organic (carbon-containing) compounds found in nature to obtain energy for their growth. Many species of soil bacteria, for example, use petroleum hydrocarbons as a food and energy source, transforming them into harmless substances consisting mainly of carbon dioxide, water, and fatty acids. Bioremediation harnesses this natural process by promoting the growth of micro-organisms that can degrade contaminants and converting them to nontoxic byproducts. The major biological processes include: enhanced anaerobic bioremediation and co-metabolic process.

##### **B.5.1.1 Enhanced Anaerobic Bioremediation**

The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated groundwater to enhance *in situ* biological degradation of organic contaminants. Nutrients, methane, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. Generally, the process includes above-

ground treatment and conditioning of the infiltration water with nutrients and methane (or other electron acceptor) source. Bioremediation has been successfully applied at hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

- Extensive treatability studies and site characterization may be necessary;
- Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones;
- The system should be used only where groundwater is near the surface;
- Bioremediation may not be applicable at sites where there are high concentrations of heavy metals, highly chlorinated organics, or inorganic salts.

Target contaminants for *in situ* bioremediation are non-halogenated volatile and semivolatile organics and petroleum hydrocarbons. Halogenated volatile and semivolatile organics and pesticides also can be treated, but the process may be less effective and may only be applicable to some of these compounds. Methane-oxidizing processes may be effective in enhancing degradation of volatile halogenated compounds.

Anaerobic bioremediation has not been demonstrated for *in situ* applications because of the difficulty in maintaining an oxygen-free environment and because of the temperature sensitivity of the microbes. Research is currently being conducted to investigate the feasibility of anaerobic degradation for aquifers.

#### **B.5.1.2 Co-Metabolic Processes**

Water containing dissolved methane and oxygen is injected into groundwater to enhance methanotrophic biological degradation. This class of micro-organisms can degrade chlorinated solvents, such as vinyl chloride and TCE, by co-metabolism. Co-metabolism is one form of secondary substrate transformation in which enzymes produced for primary substrate oxidation are capable of degrading the secondary substrate fortuitously, even though the secondary substrates do not afford sufficient energy to sustain the microbial population. Development of co-metabolic processes is at the pilot scale.

While development of bioreactors for methanotrophic TCE biodegradation is progressing well, *in situ* application has not yet been demonstrated at a practical scale. A field demonstration project has been conducted at DOD's Moffett Naval Air Station and another is being conducted at DOE's Savannah River Site.

178

The following factors may limit the applicability and effectiveness of the process:

- This technology is still under development; and
- Where the subsurface is heterogeneous, it is very difficult to circulate the methane solution throughout every portion of the contaminated zone. Higher permeability zones are cleaned up much faster because groundwater flow rates are greater.

Contaminants treated by the co-metabolic processes are halogenated volatile and semivolatile organics. Non-halogenated organics, petroleum hydrocarbons, and pesticides also can be treated, but the process may be less effective and only applicable to some compounds.

The overall cost for this technology should be in the range of \$3.00-\$10.00/1000 gallons. (\$0.79-\$2.64/1000 liters).

O&M costs can be significant because a continuous source of methane solution must be delivered to the contaminated groundwater.

#### **B.5.2 Chemical/Physical Treatments**

Physical treatment is a process in which the hazardous waste is separated from its carrier by various physical methods such as adsorption, distillation, and filtration. Physical treatment is applicable to a wide variety of wastes but further treatment is usually required. For this reason physical treatment is often discussed along with chemical treatment.

Chemical treatment is a process in which the hazardous waste is altered by a chemical reaction in order to destroy the hazardous component. Wastes that can be treated by this method include both organic and inorganic compounds without heavy metals. Drawbacks to this method include the inhibition of the treatment process reaction by impurities in the waste and the potential generation of hazardous byproducts.

The major *in situ* physical/chemical technologies include: air stripping, directional wells, dual-phase extraction, free product recovery, hydrofracturing, oxidation, and vacuum vapor extraction. Directional wells and hydrofracturing, enhancement technologies that are often used in conjunction with *in situ* physical/chemical treatment are also discussed in this section.

##### **B.5.2.1 Air Sparging**

Air is injected into a saturated matrices creating an underground stripper that removes contaminants through volatilization. The technology is designed to operate at high air flow rates in order to effect volatilization (as opposed to the lower air flow rates used to increase groundwater oxygen concentrations to stimulate biodegradation). Air stripping must operate in

tandem with SVE systems that capture volatile contaminants stripped from the saturated zone. Air stripping has been successfully implemented at hazardous waste sites.

The following factors may limit the applicability and effectiveness of the process:

- Depth of contaminants and specific site geology must be ;
- Pressure levels must be designed for site-specific conditions;
- Channeling of the air flow can occur; and
- Using air stripping without SVE could create a net positive subsurface pressure that could induce contaminant migration beyond the contaminated zone.

Target contaminants for air stripping are halogenated and non-halogenated volatile organic compounds and petroleum hydrocarbons. Only limited information is available on the process.

The overall costs should be less than \$3.00/1000 gallons (\$0.79/1000 liters). Air stripping is considered to be neither capital- nor O&M-intensive.

#### **B.5.2.2 Passive Treatment Walls**

A permeable reaction wall is installed in a excavated trench across the flow path of a contaminant plume, allowing the plume to passively move through the wall. Target contaminants for passive treatment walls are halogenated volatile and semivolatile organic compounds, and inorganics. The technology can be used, but may be less effective, in treating some non-halogenated volatile and semivolatile organics and petroleum hydrocarbons. The halogenated compounds are degraded by reactions with a mixture of porous media and a metal catalyst. Development of passive treatment walls is at the pilot scale.

The following factors may limit the applicability and effectiveness of the process:

- The technology is applicable only in relatively shallow aquifers because the trench must be constructed down to the level of the bedrock or an impermeable clay; and
- Passive treatment walls are often only effective for a short time because they lose their reactive capacity, requiring replacement of the reactive medium.

There is inadequate information to determine overall cost for this technology. Passive treatment walls are considered to be capital-intensive.

### **B.5.3 Thermal**

Thermal treatment processes may decompose hazardous components in groundwater into less hazardous or non-hazardous components. When subjected to high temperatures, organic wastes decompose to similar, less toxic forms. Complete combustion yields carbon dioxide and water plus small amounts of carbon monoxide, nitrous oxides, and chlorine and bromine acid gases. Thermal treatment is most suitable for organic wastes and is less effective when attempting to detoxify heavy metals and inorganic compounds. One drawback of thermal treatment is the high cost involved.

#### **B.5.3.1 Thermally Enhanced Soil Vapor Extraction**

Thermally enhanced SVE uses steam/hot-air injection or electric/radio frequency heating to increase the mobility of volatiles to facilitate extraction. The process includes a system for handling off-gases. Thermally enhanced SVE may be used to treat the soils in the saturated zone. Thermally enhanced SVE has been applied to contaminated soils at hazardous waste sites and is designed to treat halogenated and non-halogenated semivolatile organic compounds. Thermally enhanced SVE technologies are also effective in treating some pesticides, depending on the temperatures achieved by the system. The technology may also be used to treat some halogenated and non-halogenated volatile organic compounds and petroleum hydrocarbons, but effectiveness may be limited.

The following factors may limit the applicability and effectiveness of the process:

- Debris or other large objects buried in the media can cause operating difficulties;
- Use of the technology is limited to a slope of 5° or less;
- Performance varies depending upon the process selected because of the maximum temperature achieved; and
- The soil structure at the site may be modified depending upon the process selected.

The thermally enhanced SVE processes used by each vendor are notably different and should be investigated individually for more detailed information. Heating mechanisms employed by vendors may include, but are not limited to, radio frequency heating (Section B.4.4.2) and 6-phase heating. A 6-phase heating demonstration project is underway at RFETS; results will be available under separate cover. Since thermally enhanced SVE is an *in situ* remedy and all contaminants are under a vacuum during operation, the possibility of contaminant release is minimal.

Available data indicate that the overall cost for treatment using thermally enhanced SVE systems is approximately \$50-\$75/ton (\$55-\$82/metric ton), excluding treatment of off-gases and groundwater. Thermally enhanced SVE is considered to be both capital- and O&M-intensive.

## **B.6 EX SITU TREATMENTS**

For the *ex situ* treatment of groundwater, the groundwater would be extracted from the ground, treated in the existing onsite groundwater treatment facility, and released. The following subsections describe chemical/physical treatment and the onsite water treatment system.

### **B.6.1 Chemical/Physical**

Physical treatment is a process in which the hazardous waste is separated from its carrier by various physical methods such as adsorption, distillation, and filtration. Physical treatment is applicable to a wide variety of wastes but further treatment is usually required. For this reason physical treatment is often discussed along with chemical treatment.

Chemical treatment is a process in which the hazardous waste is altered by a chemical reaction in order to destroy the hazardous component. Wastes that can be treated by this method include both organic and inorganic compounds. Drawbacks to this method include the inhibition of the treatment process reaction by impurities in the waste and the potential generation of hazardous byproducts.

#### **B.6.1.1 Onsite Water Treatment Plant**

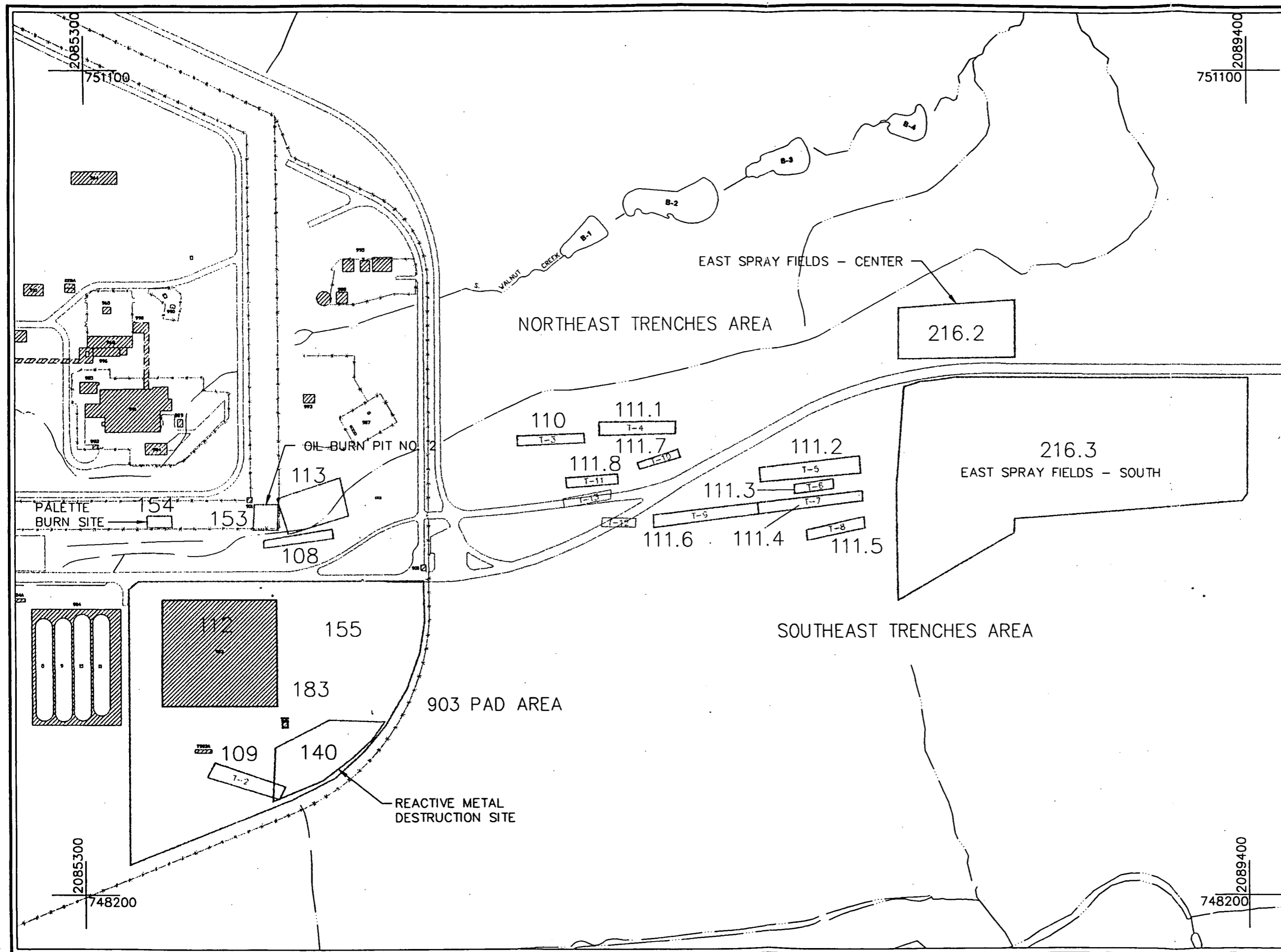
The onsite water treatment system is currently designed to process groundwater contaminated with organic and inorganic contaminants (including radionuclides). The system was specifically designed in 1989 to remove organics, uranium, and heavy metals. The treatment system consists of an influent storage and transfer system, separate treatment systems for organic and inorganic contaminants, and an effluent storage and discharge system. The first treatment system is designed to oxidize organics through an ultraviolet/hydrogen peroxide (UV/H<sub>2</sub>O<sub>2</sub>) treatment unit. The second treatment system consists of an ion exchange system that removes uranium, heavy metals, selected anions, and hardness. The system is designed for an average flow rate capacity of 30 gallons per minute (gpm) and currently operates for a normal 8-hour operating shift.

The following factors may limit the applicability and effectiveness of the process:

- The system will need to be evaluated to ensure that it can treat all of the OU2 COCs;

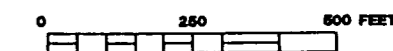
- The capacity of the system may not be adequate to handle all of the OU2 groundwater and additional site waters.

195/195



# **LEGEND**

- Streams
- Paved Roads
- ▨ Buildings
- Fence
- New IHSS Boundary
- 216.3 IHSS Identification Number

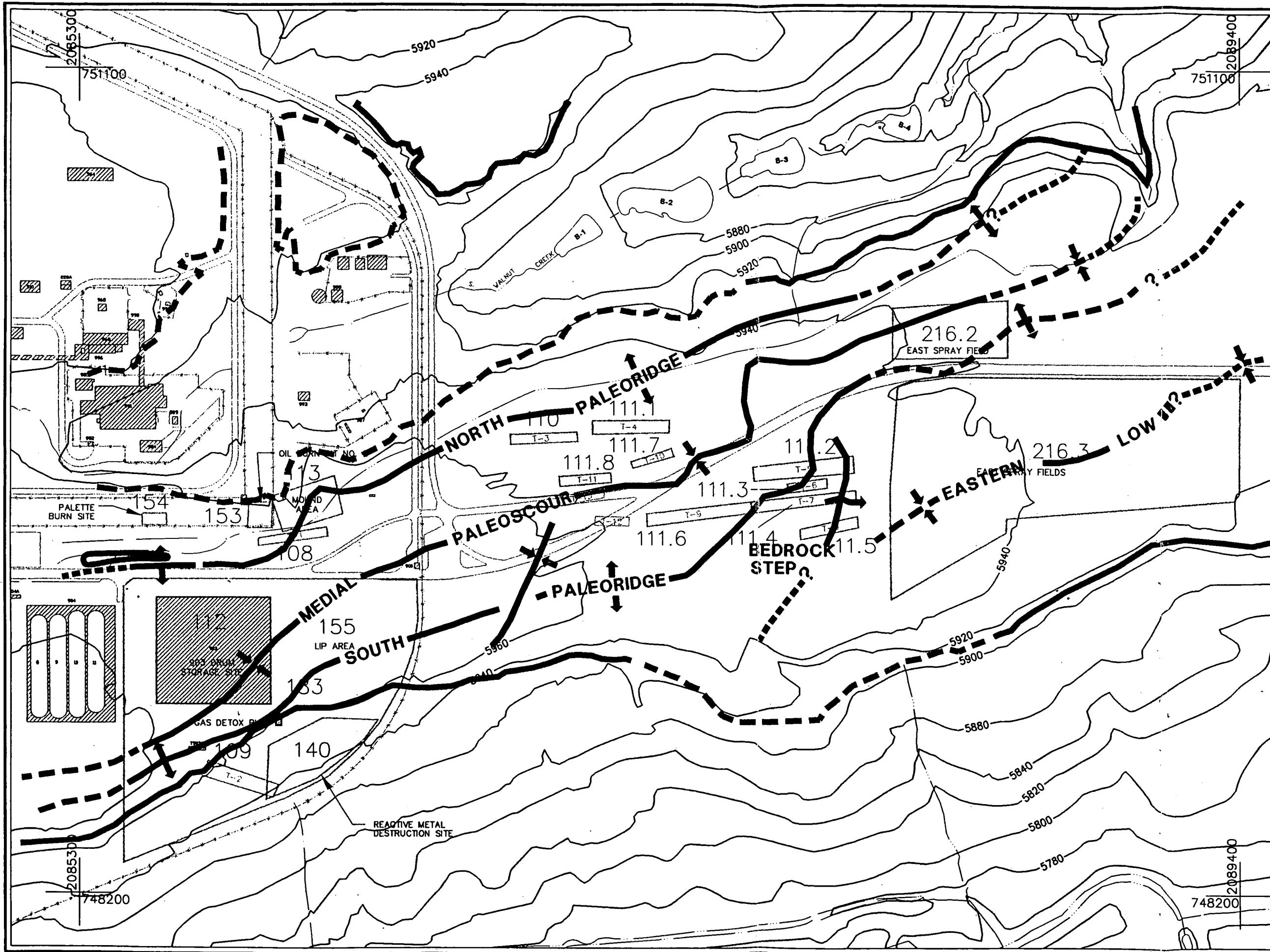


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Figure 2.2

Operable Unit No. 2  
 Technical Memorandum No. 2  
 Location of OU2 IHSSs





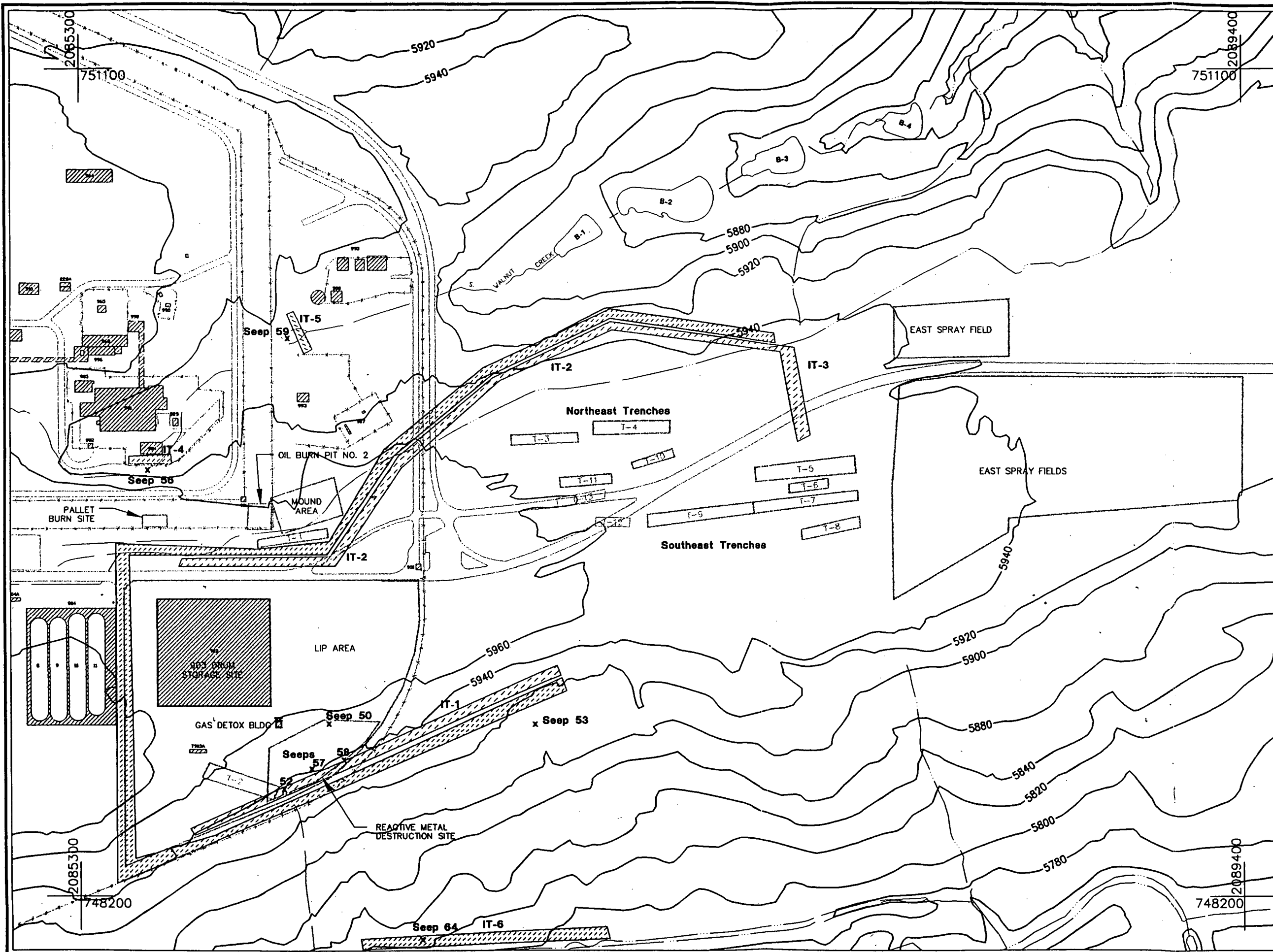
**LEGEND**

- Streams
- Paved Roads
- ▨ Buildings
- \*\*\* Fence
- New IHSS Boundary
- 216.3 IHSS Identification Number
- ▣ Areal Extent of Rocky Flats Alluvium
- Location of Crest or Trough of Top of Bedrock Features
- ▣ Dashed Where Approximate
- ▣ Extrapolated

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 TECHNOLOGY SITE  
 GOLDEN, COLORADO

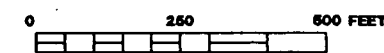
Figure 2.7

Operable Unit No. 2  
 Technical Memorandum No. 2  
 Bedrock Paleotopography



# LEGEND

- Streams
- Paved Roads
- Buildings
- Fence
- New IHSS Boundary
- Interceptor Trench
- Vertical Barrier
- Seep Location

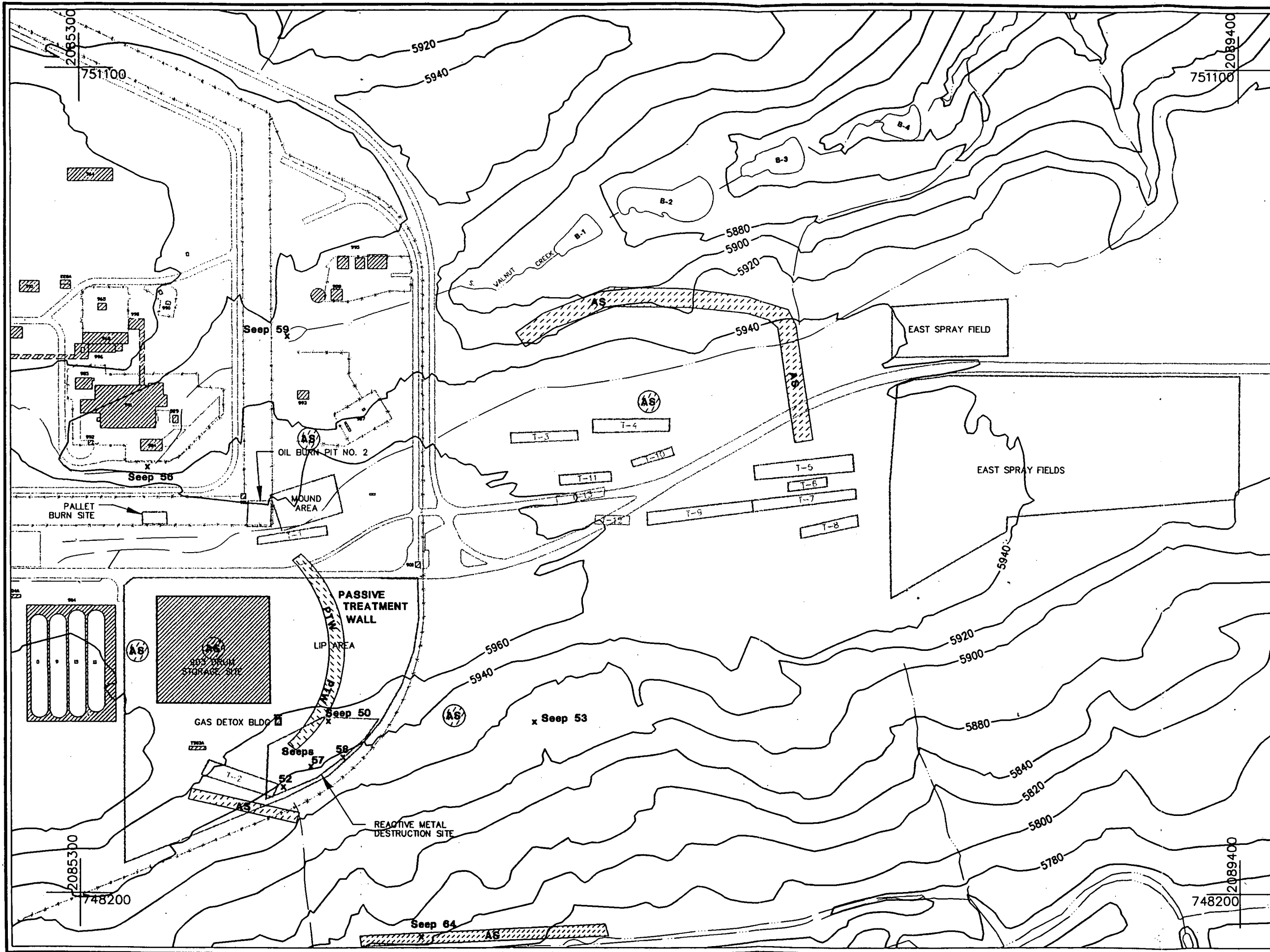


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 TECHNOLOGY SITE  
 GOLDEN, COLORADO

Figure 5.15

Operable Unit No. 2  
 Technical Memorandum No. 2

Proposed Implementation  
 Groundwater Alternative 3



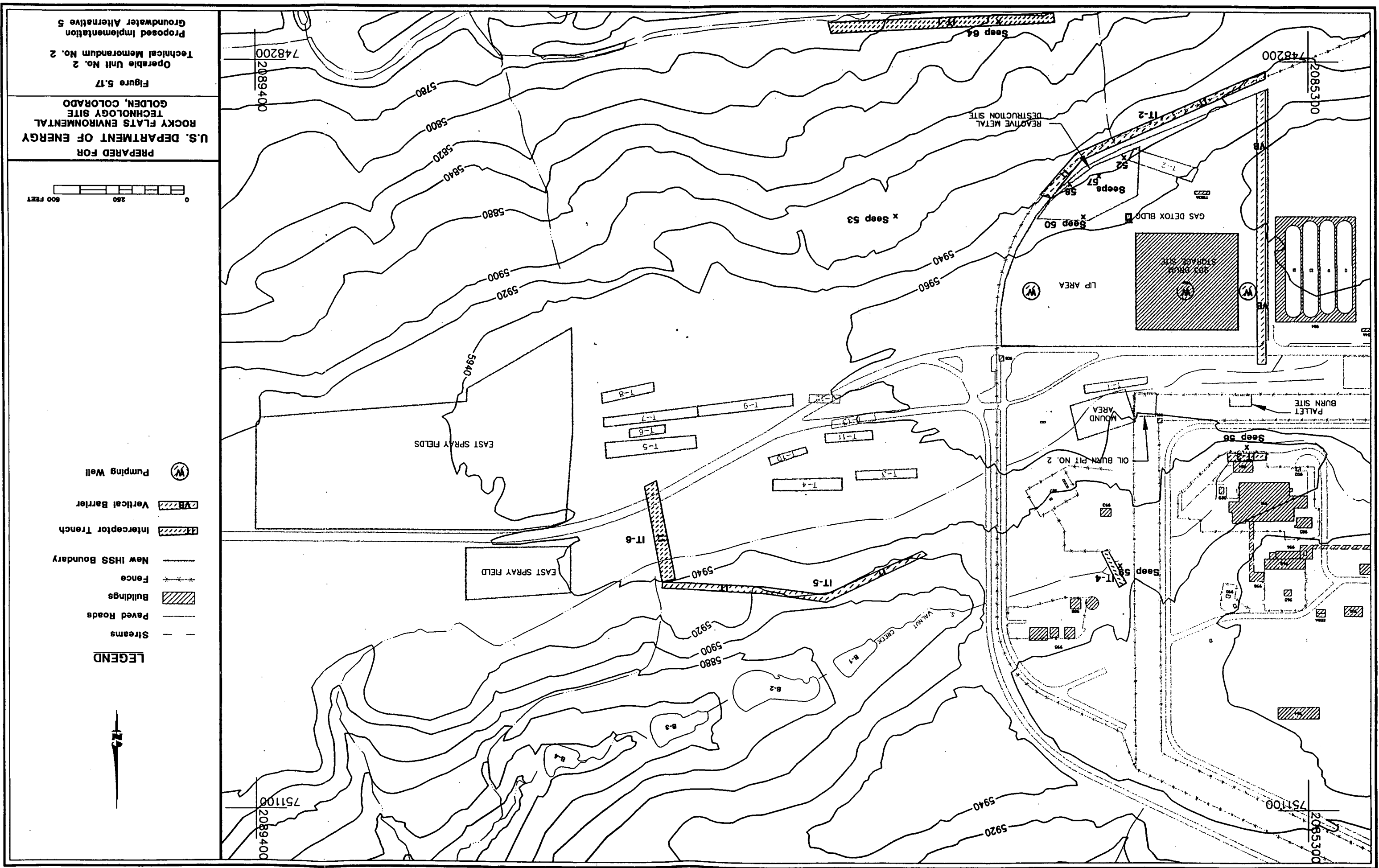
# **LEGEND**

- Streams
- Paved Roads
- Buildings
- Fence
- New IHSS Boundary
- PTW Passive Treatment Wall
- AS Air Sparging/SVE Well
- AS Air Sparging/SVE Trench

0 250 500 FEET

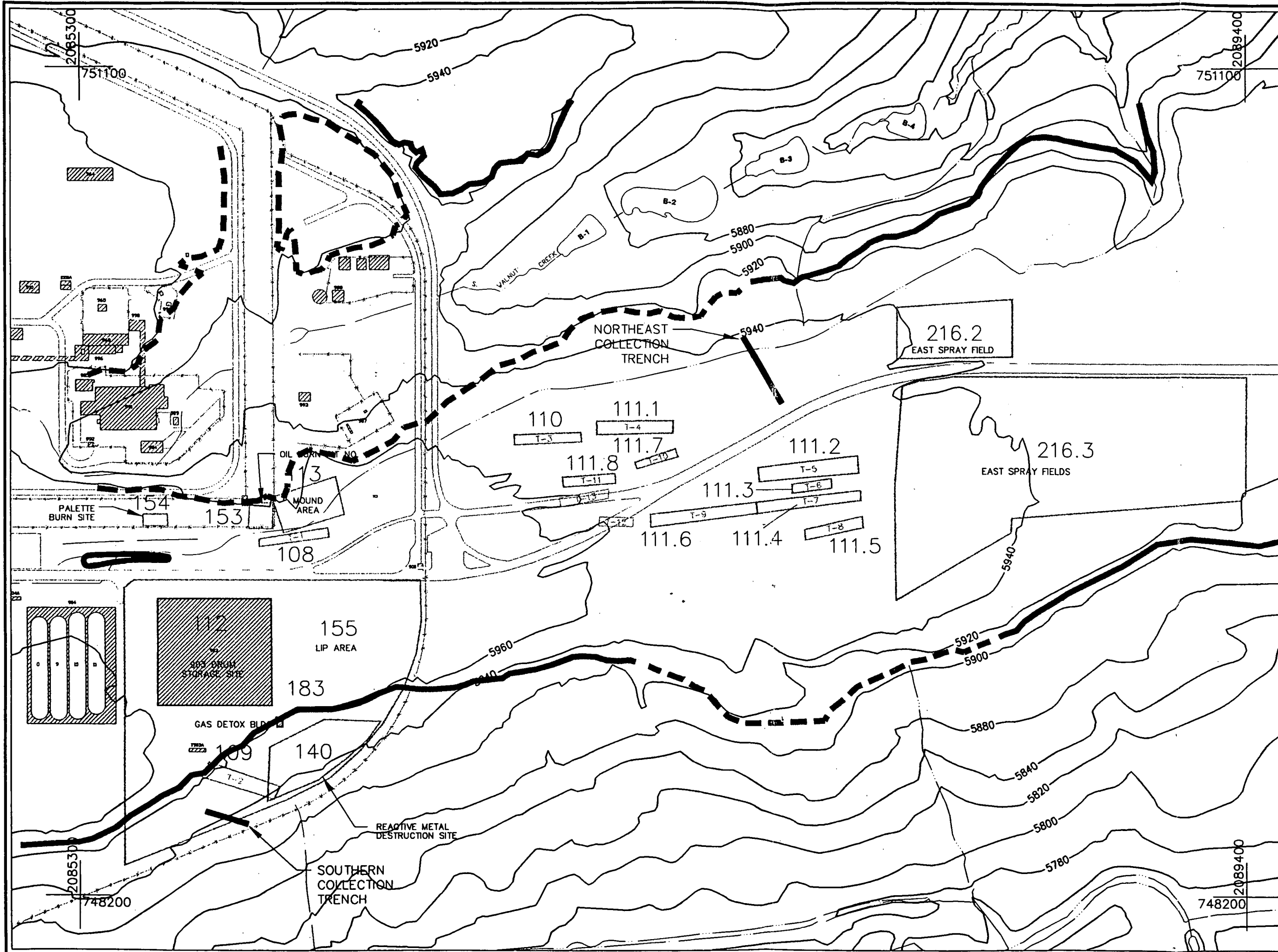
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GOLDEN, COLORADO

Figure 5.16  
Operable Unit No. 2  
Technical Memorandum No. 2  
Proposed Implementation  
Groundwater Alternative 4

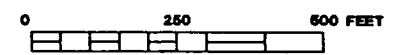


- LEGEND**
- Streams
  - Paved Roads
  - Buildings
  - Fence
  - New IHSS Boundary
  - Interceptor Trench
  - Vertical Barrier
  - Pumping Well

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GOLDEN, COLORADO  
Figure 5.17  
Operable Unit No. 2  
Technical Memorandum No. 2  
Proposed Implementation  
Groundwater Alternative 5



- LEGEND**
- Streams
  - Paved Roads
  - ▨ Buildings
  - - - Fence
  - New IHSS Boundary
  - 216.3 IHSS Identification Number
  - Areal Extent of Rocky Flats Alluvium
  - IHSS Area Boundary
  - Collection Trench



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 GOLDEN, COLORADO

Figure 5.18

Operable Unit No. 2  
 Technical Memorandum No. 2  
 Rocky Flats Alluvium/Colluvium  
 Saturated Thickness

TABLE 2.2  
PRELIMINARY REMEDIATION LEVELS FOR OU2 SURFACE SOIL

Chemical Of Concern	Background Concentration (UTL 99%)	Minimum Detection Limit I/	Potential Chemical Specific ARARs/TBCs		Programmatic Risk-Based PRG												Maximum Concentration Detected at OU2 J/	Selected Remediation Targets for OU2	Does Remediation of Contaminant Need to be Considered?
					Office Worker				Open Space Recreator a/				Ecological Researcher						
			ARARs	TBCs	RME d/		CT e/		RME d/		CT e/		RME d/		CT e/				
					NC f/	C g/	NC f/	C g/	NC f/	C g/	NC f/	C g/	NC f/	C g/	NC f/	C g/			
Aroclor-1254 (mg/kg)	0.00E+00 b/	4.40E-02	--	2.50E+01 c/	--	7.43E-01	--	5.30E+01	--	2.32E+00	--	3.62E+01	--	1.35E+01	--	4.33E+01	9.70E-01	2.50E+01	No
Aroclor-1260 (mg/kg)	0.00E+00 b/	4.40E-02	--	2.50E+01 c/	--	7.43E-01	--	5.30E+01	--	2.32E+00	--	3.62E+01	--	1.35E+01	--	4.33E+01	6.60E-01	2.50E+01	No
Bis (2-ethylhexyl) phthalate (mg/kg)	0.00E+00 b/	3.30E-01	--	--	4.09E+04	4.09E+02	4.67E+05	2.91E+04	1.54E+05	1.28E+03	7.16E+05	1.99E+04	7.44E+04	7.41E+03	2.39E+05	2.38E+04	5.10E-01	4.09E+02	No
Chromium III (mg/kg)	2.48E+01	2.00E+00	--	--	>1.00E+06 h/	--	>1.00E+06 h/	--	>1.00E+06 h/	--	>1.00E+06 h/	--	>1.00E+06 h/	--	>1.00E+06 h/	--	2.95E+01	1.00E+06	No
Americium-241 (pCi/g)	6.00E-02	2.00E-02	--	8.52E+02 k/	--	9.55E+00	--	2.49E+02	--	2.49E+01	--	2.39E+02	--	1.28E+02	--	2.36E+02	1.60E+02	8.52E+02	No
Plutonium-239/240 (pCi/g)	1.33E-01	3.00E-02	--	1.80E+03 k/	--	1.38E+01	--	9.47E+02	--	9.47E+01	--	1.53E+03	--	2.51E+02	--	7.95E+02	1.10E+04	1.80E+03	Yes

NOTES  
a/ Open Space Recreator is based on draft RME and CT values.  
b/ Background concentration for organic compounds is assumed to be zero.  
c/ TSCA (see 40 CFR 761.120 and 761.125).  
d/ RME PRG is based on reasonable maximum exposure factors.  
e/ CT PRG is based on central tendency exposure factors.  
f/ NC PRG is based on noncarcinogenic toxicity information.  
g/ C PRG is based on carcinogenic toxicity information.  
h/ RME and CT PRG values exceed 10<sup>6</sup> per year.  
i/ MDLs originate from the General Radiochemistry and Routine Analytical Services Protocol (EG&G, 1991a and EG&G, 1991b).  
j/ Maximum concentrations originate from Technical Memorandum No. 9 (DOE, 1994b).  
k/ Radionuclide value is based on office worker exposure scenario only. Calculated utilizing the programmatic PRG equation and DOE Order 5400.5; based on 100 mrem radiation dose for members of the offsite public.

**TABLE 2.3  
PRELIMINARY REMEDIATION LEVELS FOR OU2 SUBSURFACE SOIL**

Chemical Of Concern	Background Concentration (UTL 99%)	Minimum Detection Limit i/	Potential Chemical Specific ARARs/TBCs		Programmatic Risk-Based PRG				Maximum Concentration Detected at OU2 j/	Selected Remediation Targets for OU2	Does Remediation of Contaminant Need to be Considered?
					Construction Worker Exposure Scenario						
			ARARs	TBCs	RME b/		CT c/				
					NC d/	C e/	NC d/	C e/			
Arsenic (mg/kg)	1.70E+01	2.00E+00	---	---	5.32E+02	7.09E+01	2.69E+03	3.58E+02	3.03E+01	7.09E+01	No
Cadmium (mg/kg)	2.00E+00	1.00E+00	---	---	8.87E+02	> 1.00E+06 f/	4.48E+03	> 1.00E+06 f/	1.05E+01	8.87E+02	No
Mercury (mg/kg)	2.10E+00	2.00E-01	---	---	5.32E+02	---	2.69E+03	---	1.14E+02	5.32E+02	No
Tetrachloroethene (mg/kg)	0.00E+00 a/	5.00E+00	---	---	1.77E+04	2.21E+03	8.96E+04	9.04E+03	1.30E+04	2.21E+03 h/	Yes
Americium-241 (pCi/g)	2.00E-02	2.00E-02	---	7.09E+02 k/	---	2.03E+02	---	5.37E+02	2.20E+01	7.95E+02	No
Plutonium-239/240 (pCi/g)	2.50E-02	3.00E-02	---	1.56E+03 k/	---	3.01E+02	---	1.51E+03	1.80E+02	1.57E+03	No
Uranium-233/234 (pCi/g)	3.44E+00	3.00E-01	---	4.10E+04 k/	---	4.11E+03	---	1.75E+04	1.92E+02	4.93E+04	No
Uranium-235 g/ (pCi/g)	1.53E-01	3.00E-01	---	2.05E+02 k/	---	1.38E+01	---	1.73E+01	1.15E+01	2.55E+02	No
Uranium-238 g/ (pCi/g)	1.81E+00	3.00E-01	---	3.25E+03 k/	---	6.42E+01	---	8.13E+01	1.13E+02	3.93E+03	No

**NOTES**

- a/ Background concentrations for organic compounds is assumed to be zero.  
b/ RME PRG based on reasonable maximum exposure factors.  
c/ CT PRG based on central tendency exposure factors.  
d/ NC PRG based on noncarcinogenic toxicity information.  
e/ C PRG based on carcinogenic toxicity information.  
f/ RME and CT PRG values exceed 10<sup>6</sup> parts per million.  
g/ PRG values included daughter products.  
h/ Modeling will be performed to verify value meets remedial action objective of being protective of groundwater.  
i/ MDLs originate from the General Radiochemistry and Routine Analytical Services Protocol (EG&G, 1991a and EG&G, 1991b).  
j/ Maximum concentrations originate from Technical Memorandum No. 9 (DOE, 1991b).  
k/ Radionuclide value is based on construction worker exposure scenario only. Calculated utilizing the programmatic PRG equation and DOE Order 5400.5; based on 100 mrem radiation dose for members of the offsite public.

**TABLE 2.4**  
**PRELIMINARY REMEDIATION LEVELS FOR OU2 UHSU GROUNDWATER**

Chemical of Concern (Units as Indicated)	Background Concentration (UTL <sub>ms</sub> )	Minimum Detection Limit <sup>u</sup>	Potential Chemical-Specific ARARs/TBCs		Maximum Concentration Detected at OU2 <sup>u</sup>	Selected Remediation Targets for OU2	Does Remediation of Contaminant Need to be Considered?
			ARARs	TBCs			
Carbon Tetrachloride (ug/L)	0.00E+00 <sup>u</sup>	5.00E+00	1.00E+00 <sup>d</sup> 5.00E+00 <sup>u</sup>	—	2.00E+04	5.00E+00	Yes
Chloroform (ug/L)	0.00E+00 <sup>u</sup>	5.00E+00	6.00E+00 <sup>d</sup> <1.00E+02 <sup>u</sup>	—	3.90E+04	6.00E+00	Yes
1,1-Dichloroethene (ug/L)	0.00E+00 <sup>u</sup>	5.00E+00	7.00E+00 <sup>u,d</sup>	—	3.80E+02	7.00E+00	Yes
Methylene Chloride (ug/L)	0.00E+00 <sup>u</sup>	5.00E+00	5.00E+00 <sup>u,d</sup>	—	3.50E+04	5.00E+00	Yes
Tetrachloroethene (ug/L)	0.00E+00 <sup>u</sup>	5.00E+00	5.00E+00 <sup>u,d</sup>	—	1.40E+04	5.00E+00	Yes
Trichloroethene (ug/L)	0.00E+00 <sup>u</sup>	5.00E+00	5.00E+00 <sup>u,d</sup>	—	1.50E+05	5.00E+00	Yes
Vinyl Chloride (ug/L)	0.00E+00 <sup>u</sup>	1.00E+01	2.00E+00 <sup>u,d</sup>	—	8.60E+02	2.00E+00	Yes
Americium-241 (pCi/L)	3.70E-2	1.00E-02	—	3.00E+01 <sup>u</sup>	4.65E+01	3.00E+01	Yes
Plutonium-239/240 (pCi/L)	6.40E-02	1.00E-02	—	3.00E+01 <sup>u</sup>	3.55E+02	3.00E+01	Yes

**NOTES:**

- <sup>u</sup> All federal values are based on Maximum Contaminant Levels (40 CFR 141 and 142). Value for chloroform is based on the sum of all trihalomethanes (i.e., bromodichloromethane, dibromochloromethane, bromoform, and chloroform).
- <sup>u</sup> Background concentration for organic compounds is assumed to be zero.
- <sup>u</sup> Colorado Statewide Standard for Groundwater (5 CCR 1002-8, Section 3.11). All organic values are interim standards.
- <sup>u</sup> Derived Concentration Guidelines from DOE Order 5400.5, Chapter III; based on 100 mrem radiation dose for members of the offsite public. Values are based on groundwater pathway only.
- <sup>u</sup> MDLs originate from the General Radiochemistry and Routine Analytical Services Protocol (EG&G, 1991a and EG&G, 1991b).
- <sup>u</sup> Maximum concentrations originate from Technical Memorandum No. 9 (DOE, 1994b).